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AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-SECOND YEAR, 1893-94.

THURSDAY, April 12, 1894.

THE 457th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved.

The following papers were read by title:

"Moment of Inertia of Solid of Revolution," by Albert F. Hall, S.B.

"Electrical Purification of Water," by Thomas M. Drown, M.D.

The President then introduced Prof. Edward S. Morse, of Salem, who gave an account of "A New Method of Printing in Color by a Photo-Mechanical Process." Specimens of "colorityes" were shown, also prints from each of the three blocks used in the process. At the conclusion of Professor Morse's address, Mr. S. R. Koehler, of the Museum of Fine Arts, made some remarks on the theory of the process and on the general subject of printing in color.

The thanks of the Society were voted to Professor Morse, and the meeting adjourned.

THURSDAY, April 26, 1894.

The 458th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Prof. C. H. Peabody in the chair.

The records of the previous meeting were read and approved. The following papers were read by title:

"On the Determination of Nitrates in Potable Water," by Augustus H. Gill, Ph.D.

"Effect of Heat upon the Digestibility of Gluten," by E. H. Richards and Elizabeth Mason.

Voted, that the President be authorized to appoint a committee of five to nominate officers for the ensuing year.

The Chairman then introduced Major W. R. Livermore, United States Engineers, who read a paper on the "Development of Strategy and Grand Tactics in Bonaparte's First Campaign." The paper was illustrated with the lantern. At its close the thanks of the Society were voted to Major Livermore for his very interesting paper, and the meeting adjourned.

MONDAY, April 30, 1894.

The 459th meeting of the SOCIETY OF ARTS was held in the Walker Building of the Institute this day at 8 P.M., Mr. G. W. Blodgett in the chair.

The records of the previous meeting were read and approved.

The Chairman introduced Mr. Alexander Jay Wurts, of the Westinghouse Electric and Manufacturing Co., who read a paper on "Non-Arcing Lightning Arresters," with special reference to the protection of street railway circuits. Experiments were made in illustration of the principles involved, and new forms of apparatus were shown in action. The paper is printed in full in the present number of the *Quarterly*. The thanks of the Society were voted to Mr. Wurts, and the meeting adjourned.

THURSDAY, May 10, 1894.

The 460th and 32d annual meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved.

The Chairman of the Nominating Committee reported the following nominations for Executive Committee for the ensuing year: George W. Blodgett (chairman), C. J. H. Woodbury, Henry M. Howe, George O. Carpenter, and Henry C. Morse. The report was accepted.

The Chairman of the Executive Committee reported that the committee nominated Clement W. Andrews for Secretary for the ensuing year.

The Society proceeded to ballot, and these gentlemen were declared duly elected.

The report of the Executive Committee was then read, in part, as follows:

"During the 32d year of the SOCIETY OF ARTS 13 meetings have been held, numbered from 448 to 460, inclusive, with an average attendance at 11 meetings of 68 persons, the largest number at any one meeting being 140 on the evening of March 9. . . .

"The list of members is as follows:

Life members, May, 1893 . . .	83	Associate members, May, 1893 .	125
Died during the year	8	Died	1
Life members, May, 1894 . . .	75	Dropped	1
		Resigned	4
		New members elected	29
		Associate members, May, 1894 .	148

Total membership, May, 1893	208
Total membership, May, 1894	223
Net gain	15

"The Society has lost by death during the past year, among others, a member of eminent ability, great attainment, and wide reputation, Mr. Moses G. Farmer; and also one of its most constant and devoted helpers, Hon. J. A. Dresser, who was for many years one of the Executive Committee, and whose service of mind and hand was always at the disposal of the Society and always most acceptable. The Committee desire to place on record their appreciation of his self-denying interest and efficient aid.

"The *Technology Quarterly and Proceedings of the Society of Arts* has been carried on during the year under the direction of the Committee of Publication, and the former high character of the magazine has been fully sustained. The recommendation is made that the Society authorize the appointment of the Board of Publication from year to year by the Executive Committee, and the filling of vacancies therein, each board so appointed to hold office until their successors are appointed.

"The annual dues were last year reduced from five dollars to three dollars. But in spite of this reduction of forty per cent. and of the

exceptional business depression, the increase of membership has been such that the receipts from members are a little greater than last year.

For the Executive Committee,

(Signed) GEORGE W. BLODGETT, *Chairman.*"

The report was accepted and ordered to be placed on file.

In accordance with the recommendation of the Executive Committee, it was *Voted*, that the Executive Committee be authorized to appoint each year a Board of Publication, to continue for one year or until their successors are appointed.

The report of the Meteorological Committee was read, accepted, and ordered to be placed on file.

Voted, to continue the committee, adding Mr. A. Lawrence Rotch in place of Hon. J. A. Dresser, deceased.

No other business coming before the Society, the President introduced Mr. M. W. Greer, of Boston, who described the "Jones Under-Feed Mechanical Stoker." At the conclusion of Mr. Greer's paper the President introduced Mr. Henry J. Williams, of Boston, who read a paper on "Smoke Prevention." The latter paper is printed in full in the present number of the *Quarterly*.

A general discussion followed the papers, in which, among others, Messrs. H. M. Howe and W. R. Roney took part, Mr. Howe emphasizing Mr. Williams' conclusion as to the comparative cost of coal and fuel gas, and Mr. Roney calling the attention of the Society to the somewhat different qualities of coals and other inequalities of conditions in the East and West as affecting the question.

The President then extended the thanks of the Society to Messrs. Greer and Williams, and declared the meeting adjourned.

CLEMENT W. ANDREWS, *Secretary.*

NON-ARCING LIGHTNING ARRESTERS.

By ALEXANDER JAY WURTS.

Read April 30, 1894.

Part I. — An Experiment with Lightning Arresters on a 3,000-Volt Alternating Current Circuit.

Lightning storms in the West, particularly among the mountains where water power abounds, have up to the present time proved a serious drawback to the successful operation of electric light and power plants. In some instances these plants are, by reason of frequent and violent electric storms, practically inoperative during the afternoons of the summer months; and now that such far-reaching progress has been made in the construction of high potential alternating current power transmission apparatus, the subject of protection against lightning has become of vital importance. The ordinary devices which provide automatic circuit interrupting attachments, and which are still used with doubtful success on circuits of low potentials, had signally failed to do the work required of them on these high potential circuits, and it had become evident that something radically new was needed. During the winter of 1892 and 1893 I made a searching investigation of this subject, experimenting with disruptive discharges and various kinds and combinations of apparatus which might promise advantageous results, and since that time have spent nearly six months in the State of Colorado — a land of thunder storms — testing the various forms of apparatus which I had designed as a possible protection against lightning, and have also made a careful study of such phenomena as presented themselves. This work was carried out with the determination to construct, if possible, some form or combination of apparatus which should practically shut out lightning discharges from the

vital parts of a system, and thus greatly enhance the possibilities of electric power transmission.

The general requirements of efficient lightning arrester apparatus are: First, to provide discharge circuits which shall operate automatically and repeatedly, and which shall with certainty avoid dynamo short circuits or interruption of the system; second, to provide discharge circuits, or so install them that they shall invariably offer a certain path to ground for disruptive discharges in preference to any other part of the system. It follows also from this last, and as a matter of practical experience, that ground discharge circuits should be short and straight, and that ground connections should be of the most approved construction.

The difficulties in the way of meeting the above requirements on circuits of high potential seemed at first somewhat serious, in view of the fact that many of the arresters already used had not only been instantly destroyed by the short-circuiting which follows each discharge, but in many instances the arresters had been entirely ignored by the lightning, the discharges preferring an armature or converter to the spark gaps of the arresters. The correct method for overcoming this latter difficulty is to equip the system with a liberal distribution of line arresters, which, by thus affording frequent opportunities for discharge along the line, will greatly lessen the probabilities, or rather necessity, for discharging in the station. But the country over which most of these power transmission circuits are run is of such a dry, barren, and rocky character as to make it practically impossible to secure proper ground connections along the line. Fortunately, however, parts requiring protection in these power transmission plants are confined to the ends of the circuits, so that it became possible to adopt the following general plan, namely: to provide, first, an abundant discharging capacity from the line immediately before entering the station or power-houses; and second, to interpose between this point and the parts to be protected such a resistance to disruptive discharges as should make it a matter of necessity rather than of choice for these discharges to pass to earth over the discharge circuits provided for them.

The only apparatus which seemed at all available for this work was the non-arcing metal lightning arrester and some efficient form of choke coil which might be connected in the circuit between the arresters and the apparatus to be protected. As is well known, the

1,000-volt non-arcing metal lightning arrester, which is now almost universally used on alternating current circuits (see Figure 1), consists essentially of seven non-arcing metal cylinders arranged side by side with 1-64-inch spark gaps intervening. The two outside cylinders are connected to the respective sides of the circuit and the middle cylinder to the ground, thus forming a double pole arrester. For higher voltages, however, the number of cylinders must be increased in order

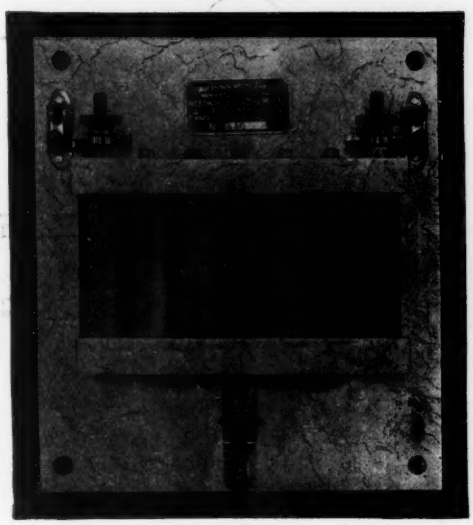


FIG. 1.

to prevent the dynamo current from following in the path of disruptive discharges. Experiments, therefore, were made to determine the number of non-arcing metal cylinders and spark gaps which would be necessary to interrupt a short-circuit on a 3,000-volt alternator with the potential raised to 3,300 volts. Nineteen cylinders, or eighteen gaps, were found to offer ample margin, and the breaking down E. M. F. on half this number of gaps, which would intervene between line and ground, was found to be about 70 per cent. of the E. M. F. required to break down insulation ordinarily used in a 3,000-volt generator. Three 1,000-volt non-arcing metal arresters were, therefore, selected as offer-

ing a convenient means of installing this apparatus (see Figure 2). It is also well known that coils, and even sharp turns in a wire, offer a high inductive resistance to disruptive discharges. Various forms of choke coils were, therefore, constructed and tested with the idea of determining those proportions which, for present requirements, should offer maximum impedance with a given length of wire. These experiments will be more particularly described in Part II. The form finally

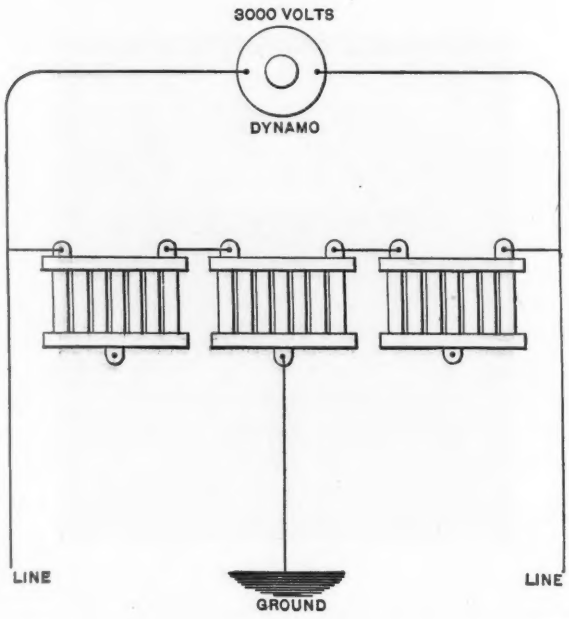


FIG. 2.

adopted was that of a flat coil about 18 inches in diameter, and wound with seventeen turns of wire; the size of the wire varied, of course, with the carrying capacity of the particular circuit into which it was to be connected. After further experimenting with various combinations of spark gaps and choke coils, it was decided that the trial apparatus should consist of eight choke coils and twelve 1,000-volt non-arcing metal arresters for each end of each circuit; that is, four choke coils should be connected in series in each leg of each circuit, with dis-

charge circuits intervening. The relative positions of these parts are clearly indicated in Figure 3, which represents one end of each of three circuits.

The theory upon which the selection of this apparatus was based will be more generally discussed in Part II; suffice it to say here that disruptive discharges form nodal points in the system, that is, points where there will be a minimum tendency to discharge; hence, to avoid

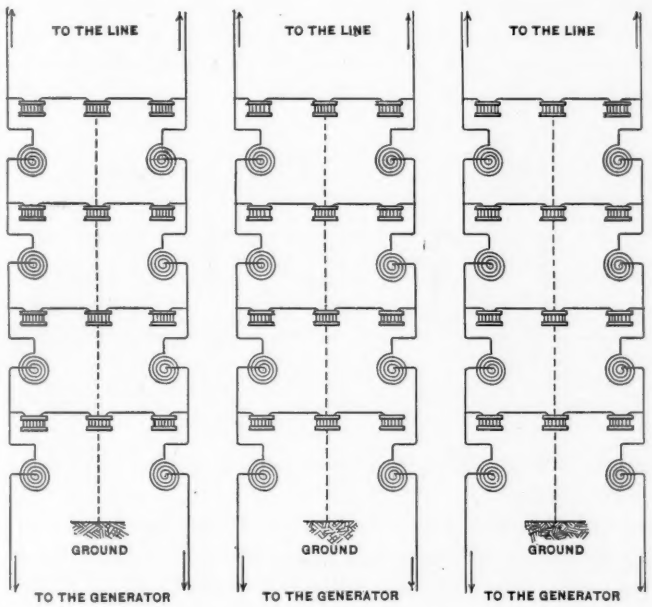


FIG. 3.

these with any degree of certainty, a multiplicity of arresters, preferably line arresters, should be used. Choke coils form points of reflection, or points where there will be a maximum tendency to discharge, hence a discharge spark gap connected directly in front of a choke coil is more likely to receive discharges than if placed at some other point in the system. Properly constructed choke coils also offer a very high resistance to the passage of disruptive discharges, so that if one or more such coils be connected between a discharge circuit and the apparatus to be protected, and if the discharge circuit or

ground wire be short and straight, the probabilities of safe discharge to earth will be vastly increased. Further, disruptive discharges are liable to divide and follow several paths, being governed by a complexity of ever varying circumstances. For this reason it was decided to connect several choke coils in series, so that should only a portion of a discharge pass across the first arrester, the balance passing through the first coil, a second opportunity for discharge would be found at the second arrester, which was also connected in front of a coil, and, therefore, at a point of reflection. Should this remaining portion of the discharge again divide, a further opportunity for discharge would be afforded at the third arrester, and so on, so that by the time the

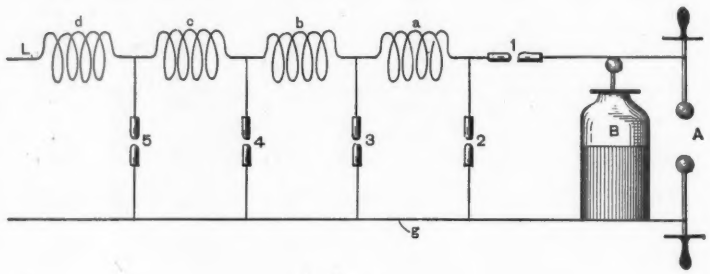


FIG. 4.

fourth coil was reached it was presumed that the discharge would have spent itself.

Some of the many experiments made to substantiate this theory are exceedingly interesting as well as instructive. Referring to Figure 4, A are the terminals of a powerful influence machine; B is a battery of Leyden jars; G a wire which may represent the ground, and is connected to the outside coating of the jars; L is a second wire which may represent one leg of an electric circuit; *a*, *b*, *c*, and *d* are choke coils connected into the line L, and in series with each other; 2, 3, 4, and 5 are intervening discharge circuits containing spark gaps; 1 is a $\frac{1}{32}$-inch spark gap separating line L from the inside coating of battery B. If now the battery becomes charged from the influence machine A, a large and violent disruptive discharge will take place across gap 1 and suddenly charge line L. This discharge will then pass to earth G through one or more of the spark gaps 2, 3, 4, 5, according to circumstances. It will be noted now that this arrange-

ment of choke coils and discharge circuits is similar to that shown in Figure 3. The spark gaps were made of rounded half-inch brass rod adjustable with a $\frac{1}{32}$-inch screw thread. The coils were wound with No. 0000 wire, were 3 inches in diameter, 6 inches long, and contained eleven turns each.

The following table indicates the very interesting results obtained by varying the lengths of spark gaps 2, 3, 4, and 5. The signs "—", "*", and "0" indicate, respectively, a heavy discharge, a feeble thread-like discharge, and no discharge.

The Spark Gap Numbers	1	2	3	4	5
The Spark Gap Lengths	12	14	1	1	1
Results, 1st	—	—	*	0	0
Results, 2d	—	0	—	0	0
The Spark Gap Lengths	12	14	2	1	1
Results	—	0	—	*	0
The Spark Gap Lengths	12	14	2	2	1
Results	—	0	—	0	*
The Spark Gap Lengths	12	14	2	2	2
Results	—	0	—	0	0
The Spark Gap Lengths	12	14	3	2	2
Results	—	0	—	*	0
The Spark Gap Lengths	12	14	3	3	2
Results	—	0	—	0	*
The Spark Gap Lengths	12	14	3	3	3
Results	—	0	—	0	0
The Spark Gap Lengths	12	14	4	3	3
Results, 1st	—	—	0	*	0
Results, 2d	—	0	—	*	0
The Spark Gap Lengths	12	14	4	4	3
Results	—	0	—	0	*
The Spark Gap Lengths	12	14	4	4	4
Results, 1st	—	—	*	—	0
Results, 2d	—	0	—	0	0
Results, 3d	—	0	0	—	0
Results, 4th	—	0	—	*	0
The Spark Gap Lengths	12	14	5	4	4
Results, 1st	—	0	—	0	0
Results, 2d	—	—	0	0	*
Results, 3d	—	—	—	—	0
Results, 4th	—	0	0	—	0
Results, 5th	—	0	—	0	*
The Spark Gap Lengths	12	14	5	5	4

Results, 1st	—	—	—	0	*
Results, 2d	—	—	0	0	*
Results, 3d	—	0	—	0	*
The Spark Gap Lengths	12	14	5	5	5
Results, 1st	—	—	—	0	0
Results, 2d	—	—	0	0	0
Results, 3d	—	0	—	0	0
Results, 4th	—	—	0	0	*
Results, 5th	—	—	0	0	*
Results, 6th	—	0	0	—	0
Results, 7th	—	—	—	0	0
The Spark Gap Lengths	12	16	5	5	5
Results	—	0	—	0	*
The Spark Gap Lengths	12	16	6	5	5
Results, 1st	—	—	—	—	0
Results, 2d	—	—	0	—	0
Results, 3d	—	0	—	0	0
Results, 4th	—	0	0	—	0
The Spark Gap Lengths	12	16	6	6	5
Results, 1st	—	0	—	*	0
Results, 2d	—	0	—	0	*
Results, 3d	—	—	—	0	*
The Spark Gap Lengths	12	16	6	6	6
Results, 1st	—	0	—	0	*
Results, 2d	—	0	—	0	0
Results, 3d	—	0	—	0	*
The Spark Gap Lengths	12	16	9	6	6
Results, 1st	—	—	—	—	0
Results, 2d	—	—	—	0	*
Results, 3d	—	—	*	0	0
Results, 4th	—	—	0	—	0
The Spark Gap Lengths	12	16	10	6	6
Results, 1st	—	0	*	—	0
Results, 2d	—	—	0	—	*
The Spark Gap Lengths	12	16	11	6	6
Results	—	0	0	—	*
The Spark Gap Lengths	12	16	10	10	10
Results, 1st	—	—	—	—	0
Results, 2d	—	—	—	0	*
Results, 3d	—	—	—	0	0
The Spark Gap Lengths	12	20	10	10	10
Results, 1st	—	0	—	—	0
Results, 2d	—	0	—	0	*
Results, 3d	—	0	—	*	0

When 1 = 12, 2 = 9, 3 = $5\frac{1}{2}$, 4 = $3\frac{3}{4}$, and 5 = 1, the sparks were about evenly divided, except that 5 never sparked alone and always gave threadlike sparks when 2 sparked. These results are represented graphically in Figure 5.

Glancing now at the above table we notice: First, the difficulty that disruptive discharges experience in passing the coils, jumping as they do large air gaps in preference to the more circuitous but infinitely better conducting paths afforded by the coils; second, the tendency for discharges to divide into two or more paths, part passing across the first or second gap and the remainder through one or more coils to a succeeding gap, showing thereby that a single choke coil does not offer certain security against the passage of these discharges; third, the uncertainty of the paths that will be selected during a series of tests where the conditions are maintained as nearly constant as possible; in fact, it seems almost impossible to produce the same results twice in succession. It is, however, to be noticed that, with these four choke coils in series and spark gaps intervening, the discharges are so thoroughly sifted out that only an occasional threadlike spark finds its way across the last gap. With laboratory results such as these, it seemed fair to presume that results more or less similar might also be expected in practice.

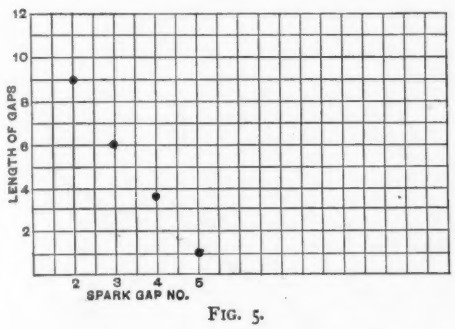


FIG. 5.

The plant selected for the trial of this apparatus was that of the San Miguel Consolidated Gold Mining Company, of Telluride, Colorado, which is equipped with a 3,000-volt alternating current synchronous system, operating stamping mills and furnishing current to the Telluride Electric Light Company. These points are situated among the mountains at distances varying from three to ten miles from the power-house. Three separate circuits leaving the power-house extend over a wild and rocky country, and in some places rise above timber line. In previous years every attempt to protect this plant from lightning had failed. During the summer months two horses were kept

constantly saddled ready for emergencies consequent on lightning discharges, and at the motor and power-house it was common practice on the approach of a thunder storm to lay out, ready for instant use, an extra armature coil, with all the necessary tools for handling the same. In one of the former types of arresters used in this plant forty fuses were blown inside of sixty minutes.

The location of each bank of arresters was selected with particular reference to securing permanently damp earth for the ground plate, the lines being led to this spot. The circuit was thus made to accommodate itself to the arresters rather than the arresters to the cir-

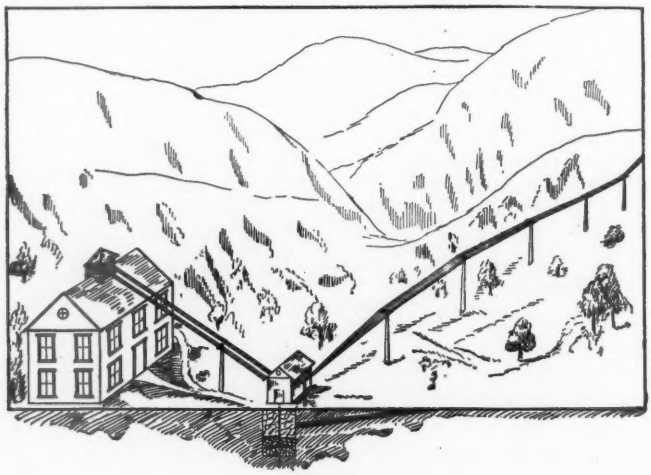


FIG. 6.

cuit. The apparatus was then installed in a specially constructed and weather-proof lightning arrester house (see Figure 6), the arresters and choke coils being mounted on thoroughly dried wooden frames, and every precaution taken to insulate these from the ground and from each other. In this manner also it was expected that the lightning discharges would be kept entirely out of the station.

The connections inside the power-house lightning arrester house are all clearly indicated in Figure 3. One main B. and S. No. 3 ground wire was used for all the arresters in each bank, unnecessary kinks and bends being studiously avoided.

The grounds which I used were of the most approved construction,

and in this respect were in marked contrast to ground connections commonly found in practice. An old rusty casting or an abandoned pulley hooked onto the end of a tangled piece of scrap wire, and then thrown into a neighboring creek, or the tail race of a mill, or a small iron spike driven conveniently into dry earth or sand, form ground connections not infrequently found in practice. But my work being only of an experimental nature, a thoroughly good ground connection was thought to be one of the essentials. The ground connections were therefore made as follows: First, a hole 6 feet square was sunk directly under each bank of arresters until permanently damp earth was reached; second, the bottom of this hole was covered with 2 feet of crushed charcoal (about pea size) — crushed coke would have answered equally well; third, over this was laid 25 square feet of No. 16 copper plate; fourth, the ground wire was then firmly soldered all the way across the ground plate; fifth, the plate was now covered with 2 feet of charcoal; and sixth, the hole then filled in with earth, using running water to settle. In one instance permanently damp earth could not be reached; water was therefore brought from some considerable distance through an iron pipe and run into the upper earth of the ground hole. In this manner the entire ground construction was maintained constantly damp.

Observations were taken by competent men at each bank of arresters during the entire lightning season, and the results obtained indicate that the discharges occurred most frequently over the second arresters; many passed over the third arresters; very few, however, over the first or fourth. The writer personally watched one of these banks of arresters through severe thunder storms, and in every instance the discharges noticed by him were seen to pass across the second series of spark gaps. The discharges followed each other across the cylinders with great rapidity, making peculiar and often startling sounds, very similar to the cracking of a teamster's whip, but in no instance was there a fuse blown or damage done to the arresters. Now these facts are not only of great practical importance, but are also exceedingly interesting when studied in connection with the results already mentioned as having been obtained with choke coils and spark gaps in my laboratory experiments. At the end of the lightning season the non-arcing metal cylinders of the arresters were carefully inspected, and the confronting sides found to be covered with minute black spots where the discharges had passed from cylinder to cylinder.

These spots were often centered with very small, smooth exposures of the metal, but in no instance was there any indication of beading or fusing together of the adjacent cylinders.

The net results of this lightning arrester experiment are most satisfactorily summed up in the following letter written by Mr. P. N. Nunn, Electrical Engineer of the San Miguel Consolidated Gold Mining Company. I feel greatly indebted to Mr. Nunn for the kindly assistance he has rendered in carrying out these tests, and take this opportunity to again thank him for his valuable suggestions and the painstaking care with which the installation was made.

THE SAN MIGUEL CONSOLIDATED GOLD MINING CO.

TELLURIDE, COLO., October 12, 1893.

MR. ALEXANDER JAY WURTS,
Pittsburg, Pa.

My Dear Sir: — In reply to your inquiry respecting the results obtained from your lightning arresters in the operation of our electric power transmission plant, we take pleasure in making the following statement:

At the present time, as you are aware, our plant consists of a power-station at Ames, equipped with Westinghouse alternating current generators of 1,100 horse power capacity, which supply current for synchronous motors in three stamp mills at distances of two, three, and ten miles respectively, and for lights in the town of Telluride about eight miles distant. The pole line runs over the mountains in altitudes varying from 8,800 to 12,000 feet above the sea level, traversing at different places bare ridges of mountain divide, and large tracts of magnetic mineral. It is thus peculiarly exposed to lightning in a district where lightning is of extraordinary frequency and force at certain seasons of the year.

The difficulties of the situation are further aggravated by the fact that we generate and utilize without transformation, except for lighting purposes, an alternating current of 3,000 volts.

Despite the use of an overhead grounded wire on our pole line and the best arresting apparatus we could procure, we suffered continual interruptions during the lightning seasons of 1891 and 1892. On one occasion five armature coils were burned out in a single storm. With any other form of armature this would have meant five burned out armatures, but with the toothed armature of your machines it represented the cost of five new coils and a day's delay. The frequency of the discharges of lightning was so great that the insulation in the highest grade of cables and cores throughout the entire apparatus became so honeycombed with perforations as to give rise to continual leakage, grounds and short circuits requiring constant and expensive repairs and causing prolonged delays.

Since putting in your non-arcing metal arresters in connection with your system of specially designed choke coils, we have passed through the lightning season of 1893 without a particle of lightning having passed to our knowledge beyond the arresting apparatus, without a shut-down, without the loss of a coil, and without a single perforation of insulation. The experience of this season has given us the greatest confidence in the efficiency of your apparatus as a protection against lightning.

(Signed) P. N. NUNN,
Electrical Engineer.

PART II. — PROTECTION AGAINST LIGHTNING ON CIRCUITS OF ANY POTENTIAL.

A system of protection against lightning discharges has been designed by the writer, which is applicable to circuits of any potential, and, although this system has not yet received a practical test, the indications are that it will prove efficient.

The proposition is to connect in series with the circuit, and at frequent intervals, a system of properly constructed choke coils, the expectation being that the energy stored in the circuit in the form of static electricity will, at moments when there is a tendency to a disruptive discharge, dissipate itself into heat through the electrical surgings which will be set up between and among the several choke

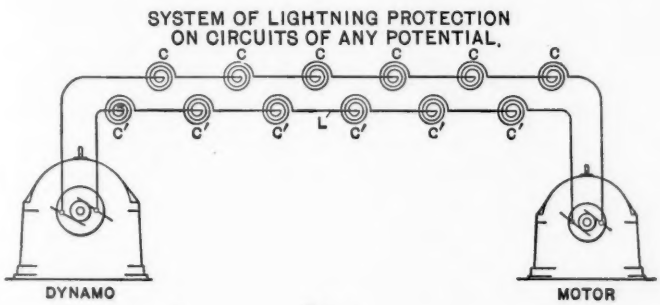


FIG. 7.

coils. In Figure 7 there is represented a power transmission circuit provided with this system of protection against lightning.

The theory upon which these predictions are based is more or less familiar to every electrical student. There exist, however, differences of opinion regarding some of the points involved. Many of my impressions are derived from personal observation, and through these I have been led to believe that, in many cases, electric circuits become statically charged by contact with the neighboring charged atmosphere, that is, by conduction from it. The charge on the line, no doubt, leaks to earth; so does the charge in the atmosphere; but the two are maintained at practically the same potential.

The potential of the atmosphere surrounding the wires of overhead electric light and power circuits is not very high. At the top of

Washington monument, Washington, D.C., the difference of potential between the atmosphere and the earth during the thunder storms is about 3,000 volts. If, then, the potential of an aërial wire is the same as that of the atmosphere intimately surrounding it, the immediate source of danger from the static strain will be inconsiderable. When, however, a lightning discharge occurs from the clouds, this charged condition of the wire becomes unbalanced, the atmosphere has been discharged, and its potential has suddenly sunk to zero. The static charge in the wire having lost the support of the previously charged atmosphere now seeks an equilibrium, and in so doing sets up electrical waves which travel to the extremities of the system, or to points of great resistance, and are there reflected to other parts to be again reflected, and so on. At these points of reflection there is an enormous strain and a consequent tendency to "side flash," so often causing the damage to insulation which we are seeking to avoid. Such electrical disturbances consequent upon a lightning discharge can be observed in wire fences and in tramway rails. In high altitudes even the wet rocks are seen to become luminous, giving off brush discharges at moments of electrical disturbance; and the human body will often feel that peculiar sensation familiar to those who handle influence machines, namely, a sudden and cool draught when an existing condition of electrical strain is broken down.

It is then at these points of reflection that the damage is done and that we get the impression of a very high potential. An armature insulation is pierced by the discharge, the dynamo current follows, there is a great flash accompanying the short circuit, several fuses let go, and the superintendent is informed that lightning entered the station. As a matter of fact, it is probable that the discharge has made a hole in the insulation no larger than the prick of a pin or perhaps that of a pin head, which in most cases is greatly enlarged by the dynamo current.

There are other methods, however, by which circuits probably become charged, namely, by static induction from clouds and by dynamic induction from cloud discharges. It is probable that these also set up electrical surgings in the circuit, and that the danger to insulation occurs at points of reflection. I am also inclined to believe that, although a line is seldom, if ever, struck by a direct lightning discharge, it occasionally becomes charged by some of the ramifications which are often seen to accompany a lightning stroke.

Figure 8 is an example of what might be called a direct discharge, and to the best of my knowledge there is no evidence to show that such discharges strike electric wires. In Figure 9 there is represented a lightning discharge accompanied by ramifications which wander off in a seemingly aimless manner, but which, no doubt, find their way to bodies or strata of air variously electrified. I am inclined to believe that at times some of these ramifications find their way into electric circuits.

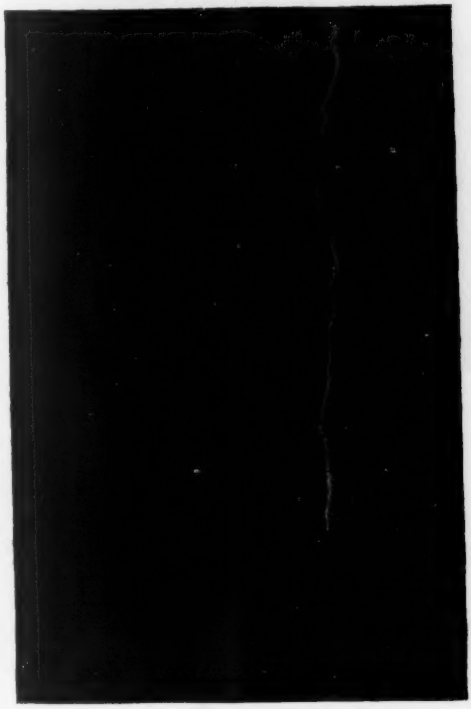


FIG. 8.

A curious freak which came under my observation last summer is illustrated in Figure 10. T represents an overhead trolley wire, on either side of which are wooden poles; H is a bell-shaped insulator made of compressed mica and shellac. These insulators easily withstand an electric strain of 12,000 volts. R is an iron ring holding the span wire to the pole; B is a branch circuit feeding current to a group of lamps G^1; and L is a lightning arrester in its discharge circuit. G^2 is a second group of lamps. The distance between H and B is about 50 feet. After a violent thunder storm it was noticed that one of these poles had been shattered from the top down to the iron ring, the remaining portion being uninjured. This had been done by lightning, and, in the opinion of the writer, by one of the ramifications to which allusion has already been made. In any case, this discharge, whatever it may have been, passed over the span wire to the bell insu-

FIG. 9.

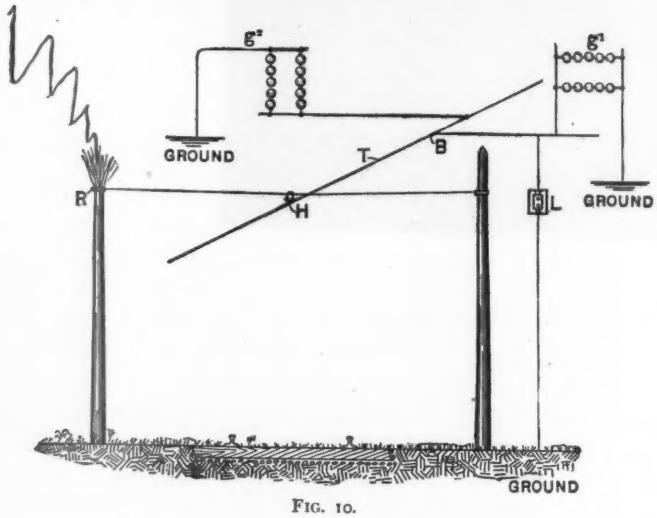


FIG. 10.

lator H, piercing it and breaking it into three pieces, then traveled along the trolley wire to B, where it apparently divided, one part passing to the group of lights G^2, breaking them all, ten in number, and the other part to earth through the arrester L, without in any way interfering with the group of lights G^1. It is quite remarkable to note that none of the parts damaged by this discharge showed any indications of heat.

During the past summer I have watched many discharges enter a generating station and pass to earth across simple carbon spark gaps provided with No. 18 copper wire fuses. The discharges gave a crackling sound similar to that of discharges from a Leyden jar, and in some instances where I had placed pieces of tissue paper between the electrodes of the spark gaps the papers were perforated with small holes. In one instance only which came under my observation did the copper wire fuse melt. An apparently prolonged discharge passed over one of the spark gaps with a hissing sound, raised the tips of the carbon electrodes to a white heat, and fused the copper wire cut-out, the time taken being approximately two seconds, which would indicate in the neighborhood of 150 amperes. I believe this discharge to have been part of a true lightning discharge — one of its ramifications — but in the great majority of cases the discharges are small, and in this respect bear no comparison to cloud discharges.

Now, if the "electrical surgings" theory be correct, I believe that these dangerous points of reflection can, by means of properly distributed and effective choke coils, be confined to long lines and made to wear themselves out, as it were, between the coils. In this manner frequent points of reflection would be distributed over the system. Primary waves set up during electrical disturbances would be broken into smaller waves, which, surging back and forth between the coils or points of reflection, would finally become dissipated and their energy pass off into heat.

The number of coils which it would be necessary to use for a given length of circuit has not yet been determined, but the writer would suggest placing four to each mile of single wire. For convenient accommodation on the poles these can be arranged alternately on the two legs of the circuit, thus avoiding two coils on any one pole.

Should such a system of protection against lightning be found efficient, its many advantages over the discharge circuit method would

be obvious, particularly in a country where good ground connections are costly and often impossible to construct.

The general form and dimensions of these choke coils is a matter of considerable importance. Dr. Lodge states, I believe, that for dis-

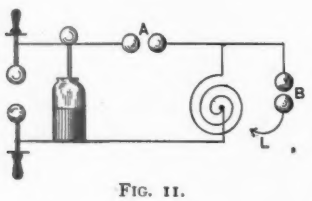


FIG. 11.

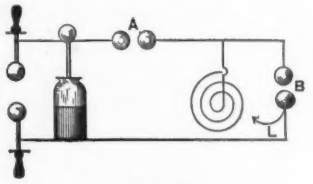


FIG. 13.

ruptive discharges a flat spiral will offer maximum impedance with a given length of wire. To the best of my knowledge, however, Dr. Lodge makes no mention of the number of turns which may be advantageously used. I have found by experiment that the impedance or resistance to the passage of disruptive discharges does not continuously increase with the number of turns, but that a critical point is rapidly reached, beyond which additional turns do not add appreciably to the impedance of the coil. The critical point was determined in the following manner. A large flat coil was constructed, having the following specifications:

Size of wire	No. 0
Number of turns	34
Outside diameter	30″
Inside diameter	3″

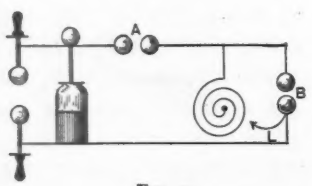


FIG. 12.

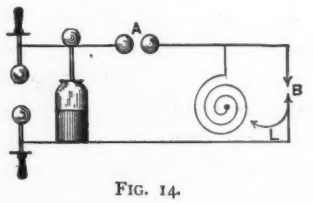


FIG. 14.

The wire was carefully insulated so that the discharges could not pass between consecutive convolutions.

This coil was then connected up in the usual manner for determining impedance, the general arrangement of the apparatus being shown in Figures 11, 12, 13, and 14, where B is a variable shunt spark

gap, one terminal of which is permanently connected to either terminal of the coil, while the other is provided with a sharp metallic point fastened to a short flexible cord. The sharp point was used to pierce the insulation of the coil, thereby reaching the copper of any convolution and also in this manner providing a means for shunting any desired portion of the coil by the spark gap B. Spark gaps A and B were varied by means of a thirty-second of an inch screw thread, so that the dimensions of these gaps are given in thirty-seconds of an inch.

Each determination was made by shunting with the gap B that portion of the coil whose impedance was desired, and then varying the length of B until the discharges were about evenly divided between the coil and the gap. In the following table are given the values of B and the number of convolutions shunted by the gap in each determination.

No. of Turns.	1st B.	2d B.	3d B.	4th B.	5th B.
1	¼	2	¼	½	¾
2	1	3¾	1	1	1½
3	1¾	5¼	2	2	2½
4	2½	6½	3	3	3½
5	2¾	8½	4	4	4½
6	3¾	10½	5	7	6
7	3¾	11	5½	9	6¾
8	4¼	11	6½	11	7½
9	5¼	11	7	13	8½
10	6	11	7¾	14	9¾
11	6½	11	8	15	10½
12	7	11	9	17	11¼
13	7½	11	9½	18	13
14	8	11	10	20	13
15	8¾	11	11	20½	13
16	9	11	11½	20½	13
17	9	11	11½	20½	13
18	9½	11	11½	20½	13
19	10¼	11	11½	20½	13
20	10¼	11	11½	20½	13
21	10½	11	11½	20½	13
22	10½	11	11½	20½	13
23	10½	11	11½	20½	13
24	10¾	11	11½	20½	13
25	10¾	11	11½	20½	13
26	10¾	11	11½	20¾	13
27	11	11	11½	20¾	13
28	11	11	11½	20¾	13
29	11	11	11½	21	13
30	11	11	11½	21	13
31	11	11	11½	21	13
32	11	11	11½	21	13
33	11	11	11½	21	13
34	11	11	11½	21	13

In the first column is given the number of convolutions shunted by the spark B.

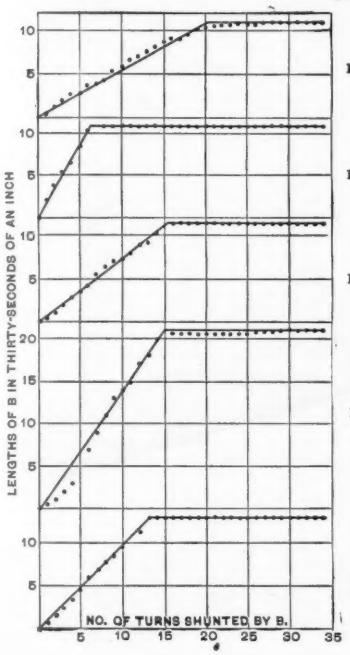
Column 1 B gives the values of B under conditions shown in Figure 11, with A equals 12 and with rounded electrodes at B.

Column 2 B gives the values of B under conditions shown in Figure 12, with A equals 12 and with rounded electrodes at B.

Column 3 B gives the values of B under conditions shown in Figure 13, with A equals 12 and with rounded electrodes at B.

Column 4 B gives the values of B under conditions shown in Figure 14, with A equals 12 and with sharp electrodes at B.

Column 5 B gives the values of B under conditions shown in Figure 13, with A equals 15 and with rounded electrodes at B.



FIGS.
15
16
17
18
19

For convenience these results are graphically represented in Figures 15, 16, 17, 18, and 19, and we note, first, that in each case a positive maximum impedance is reached, beyond which additional turns do not affect the results; second, that, with the exception of the results shown in Figure 15, the impedance does not increase beyond about the seventeenth turn; third, that, with both terminals of the coil permanently connected to the discharge circuit (see Figure 15), the increase of impedance is more gradual than when only one terminal is so connected; fourth, that when permanent connection is made to the outside of the coil (Figure 16) the increase is more rapid than when permanent connection is made at the center (Figure 17) — in other words, a single turn on the outside offers more impedance than a single turn nearer the center; for equal lengths of wire, however, the turns near the center offer greater impedance — fifth, that increasing A slightly decreases the number of turns (Figure 19); sixth, that using points at B, instead of knobs, does not materially change the results, other than to make the path selected by the discharge somewhat more uncertain, as will be noticed by the irregular curve shown in Figure 18.

The coils which I have constructed have been wound with reference to the critical point.

Dr. Lodge has also experimented with such coils in connection with iron cores, and found that the impedance is not appreciably affected by their introduction. I have also experimented in this line, and have naturally surprised myself by obtaining quite different results. It is, however, to be supposed, in view of Dr. Lodge's masterly study of this subject, that my conditions have in some way differed from his. I found that upon the introduction of a small bundle of iron wires into the core of a coil the impedance to disruptive discharges was

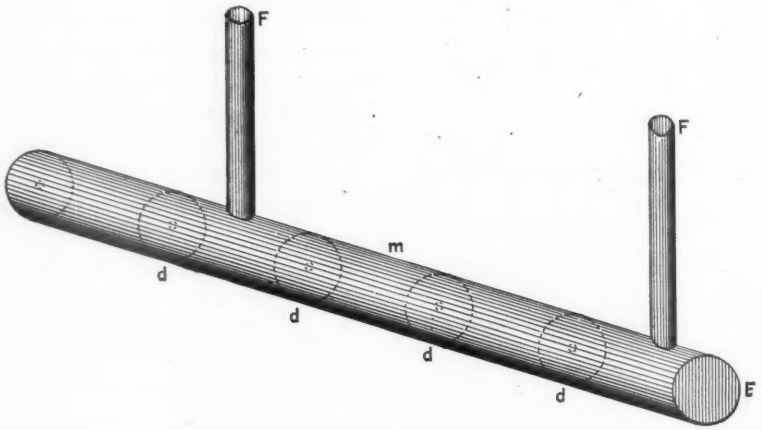


FIG. 20.

reduced nearly 20 per cent. The cause of this was at once made apparent by the beautiful sparks which were seen to appear among the iron wires of the core upon the passage of each disruptive discharge. These iron wires, of course, form among themselves closed secondaries to the primary coil, and in this manner also very beautifully illustrate the oscillatory character of the discharge.

A convenient mechanical analogy for this electrical surgings system may be found in hydraulics. Referring to Figure 20 let M represent a water main closed at either end; F F a supply and outlet; *d d*, etc., perforated elastic diaphragms. If now an impulse be imparted to the water at E, as by a blow, a wave will tend to travel from one end of the main to the other, and if it were not for the dia-

phragms this wave would either burst out the opposite end of the pipe or be reflected back and forth until the energy of the wave had become transformed into heat. The presence of the diaphragms, however, will tend to break up the initial wave and confine the surgings to comparatively small portions of the pipe. At the same time the perforations in the diaphragms allow of a continuous flow of water under pressure. In the electrical system the choke coils are supposed to break up the electrical surgings, much as these diaphragms break up the water surgings, and at the same time the coils do not materially interfere with the passage of the dynamo current. The coils cause points of reflection to occur where an excessive static strain can do no harm. The ends of the circuit, which are the vital parts of an electric power transmission system, are thus shielded by the coils and the energy of the static charge is harmlessly transformed into heat.

It has, however, been mentioned in Part I that coils are not absolutely impervious to disruptive discharges. A discharge entering a coil meets with continuous resistance, and is finally all or partially reflected; in other words, a coil is not a stone wall, does not necessarily confine the point of intense electrical strain to the first inch or two of the coil. The discharge penetrates the coil, and often causes "side flash" to occur well within its interior. In my mechanical analogy, therefore, I have represented this yielding opposition, as it were, by elastic diaphragms.

Part III. — Discriminating Lightning Arresters.

The Condenser Lightning Arrester. — The discovery and practical application of non-arcing metal to alternating current circuits about two years ago[1] has indicated the possibility of constructing a discriminating lightning arrester, as it were, for direct current circuits; that is, an arrester which should not require the usual automatic circuit interrupting attachment, but which, by virtue of its material or construction, should allow static electricity to pass and prove an effectual barrier to the dynamo current.

The first step taken in this direction was to carefully analyze the conditions, and the general conclusions arrived at were as follows: A circuit becomes charged in various ways with static electricity tending to earth. These charges are, in a majority of cases, small and of

[1] Transactions of the American Institute of Electrical Engineers, 9 (1892), 102.

no considerable intensity. The surgings in the system find points of reflection, which also become points of greatly increased tension. The earth is the great reservoir (to use common language) for these discharges. This reservoir is, however, unnecessarily large for the accommodation of line discharges. Might not smaller reservoirs be made — little earths insulated from the mother earth? If the circuit were connected directly or through spark gaps to such little earths, these dangerous surgings might be broken up and the line safely discharged without a possibility of the dynamo current following. Each spark gap in each of such discharge circuits would then form a discriminating lightning arrester, but these little earths would be nothing more nor less than one coating of a condenser — the mother earth a common coating to them all. Why not, then, use condensers, connecting one side to line, the other to earth through a spark gap?

One difficulty immediately presented itself. After the condenser had become charged, how was it to become discharged? To be successful it must be self-discharging, and not only this, but the discharge must take place in such a manner that no dynamo current should follow. Therefore, to discharge the condenser disruptively was at once out of the question. Experiments in this line led first to the application of a wet string to the terminals of a condenser, the idea being to leak out the charge through an ohmic resistance sufficiently great to prevent an appreciable flow of dynamo current. A two M. F. condenser provided with a wet string leak was treated with violent disruptive discharges from a battery of Leyden jars, and upon immediately applying the tongs to the terminals of the condenser after the crack of the discharge not the smallest trace of a charge could be detected. When the string was removed or had become dry the charge was retained. Evidently a wet string would not answer as a permanent leak. Various compositions of plumbago with molding sand, red lead, and plaster of Paris were pressed into a tube and used; but these all proved unsatisfactory, being unreliable. In many instances this composition leak would, before testing with the condenser, have a resistance of 30,000 ohms, and after a single discharge it would be found that this resistance had increased to many hundred thousand ohms. This was, perhaps, due to the flying apart of the plumbago particles under the influence of the discharge, and so breaking the continuity. Finally, a pencil mark over ground glass was suggested, and this was found to work admirably. A medium pencil was rubbed back and forth over

a strip of ground glass, making a narrow shining streak having a resistance of from 40,000 to 50,000 ohms. Rubbing with the hands did not seem to appreciably change this resistance. Broad black pencil marks were made on the ends for better contact, and connection to the terminals of the condenser was obtained through aluminum foil, both glass and foil being protected on the bottom by the wooden case of the condenser and on top by a small inverted wooden trough. A condenser provided with such a pencil mark leak was now connected to a 500-volt direct current circuit and to apparatus, as shown in Figure 21. A was a 500-volt direct current generator; L one leg of the circuit, which may represent a trolley wire; G the other leg of

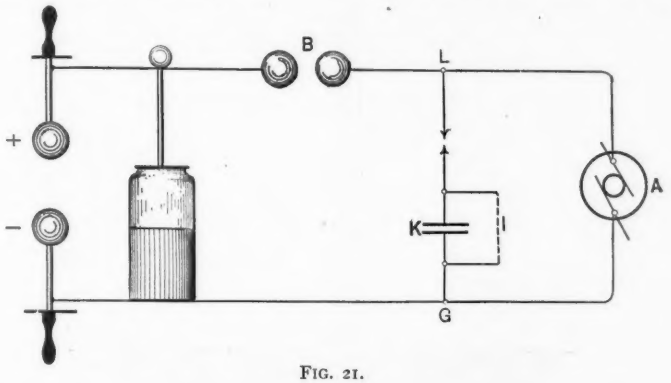


FIG. 21.

the circuit, which may represent the ground return; K the two M. F. condenser with its high resistance leak *l*; C a small spark gap in series with the condenser and in the discharge circuit; B was a $\frac{12}{32}$-inch spark gap over which disruptive discharges would pass from the battery of Leyden jars (11), and in this manner suddenly charge the line L. The most violent disruptive discharges that could be obtained in the laboratory were unable to damage either the generator or the condenser. A small spark gap, a trifle larger than C, connected either in series or in shunt to the generator, failed to take any of the discharges, thus demonstrating the ease with which the discharges were received by the condenser. Such tests were continued for half an hour at a time, the discharges following each other in rapid succession; but the condenser was ever ready, being kept constantly discharged by the high resistance leak. Of course, the resistance of the leak was sufficient to prevent the formation of an arc at C. The ter-

minals of the leak were also too far apart to permit the condenser to discharge disruptively. This device insures all the requirements of a discriminating lightning arrester, and in this form seemed admirably adapted for station and indoor use on 500-volt direct current circuits.

For line or outdoor use the condenser was placed in a suitable cast-iron box, one terminal of the condenser being grounded to it,

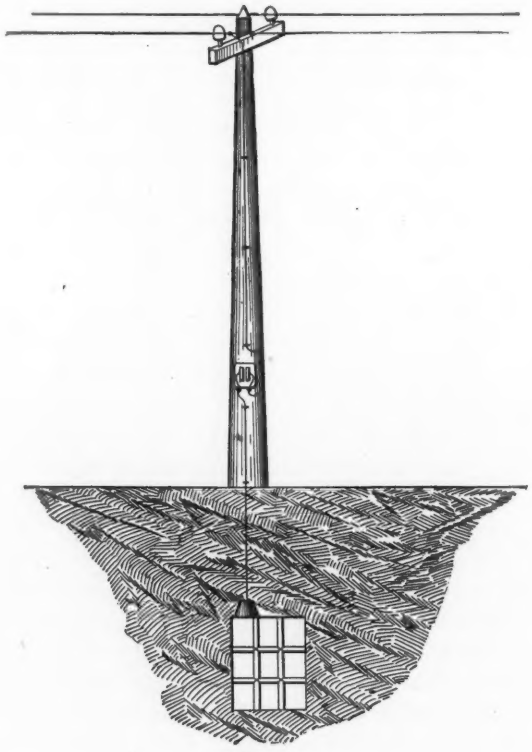


FIG. 22.

while the other was led out through a specially designed and water-tight bushing. If, then, this iron box were buried in damp earth, as a ground plate, so to speak, the outer terminal connected to the lower electrode of a small spark gap placed on a pole, and the upper electrode of the gap connected to the line, the combination would constitute a discriminating line lightning arrester. See Figure 22.

Practical tests have been made during the past summer with both station and line condenser lightning arresters, and the results obtained have been most gratifying. The plant in which the apparatus was installed was that of the Denver Tramway Company, Denver, Colorado, in a locality where lightning storms are particularly severe and of frequent occurrence. This plant extends over a vast amount of territory, and no attempt was made to protect it as a whole with these arresters. The experiences of this company with automatic lightning arresters on the line had been extremely unsatisfactory, and as a final measure they had resorted to simple carbon gaps liberally distributed over the system, depending upon the station circuit-breakers to interrupt the short circuits. This combination, however, worked satisfactorily near the station only; at any considerable distance therefrom the drop on the line was such that even a short circuit across these spark gaps failed to trip the breakers. The arc therefore continued until it had burned itself out, which in many cases was not accomplished until the top of its wooden pole had been burned off.

The installation of these condenser lightning arresters consisted of five arresters on the line, and forty-four spark gaps with eleven condensers in the station. The station spark gaps were also provided with two specially constructed choke coils for each feeder. The original arrangement of this apparatus is shown in Figure 23. A is the generator; F F, etc., the feeders; 1, 2, 3, 4, etc., the forty-four spark gaps alluded to; C 1, C 2, the two choke coils in series with each feeder; S represents the circuit-breakers and K Keystone lightning arresters; C is a bank of four 2 M F condensers, making a common ground for the forty-four spark gaps; T is a tank lightning arrester; G is an overhead ground return; 5 a spark gap in the ground wire of the forty-four spark gaps. A telltale piece of tissue paper was placed in this gap, which, becoming punctured, would at once indicate and register the passage of a discharge across any of the forty-four spark gaps.

The first thunder storm which occurred after this apparatus had been installed gave unlooked for results. The telltale paper at 5 failed to indicate any discharge whatever; the spark gaps 1, 2, 3, and 4, which were placed in the cupola, were examined, and many of these found to be badly burned. At first thought this indicated some path to earth other than that provided through gap 5 to the

condensers. Tests for a ground, however, failed to prove this to be the case. A succeeding storm reproduced these same strange results. A more careful study of the problem now disclosed the fact that as the circuit-breakers were frequently thrown open during thunder storms, the feeders which were thus opened became ground wires, being grounded through their respective motors. Consequently live feeders discharged into these dead or grounded feed-

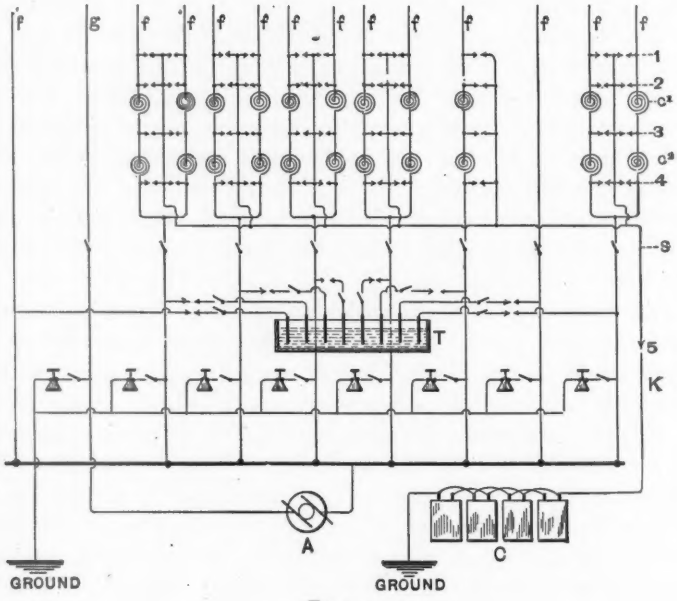


FIG. 23.

ers and *vice versa*, forming arcs which burned the carbon electrodes of the several spark gaps according to the amount of current taken by the respective feeders.

Fresh carbon electrodes were subsequently provided and a single condenser connected to each group of spark gaps on the individual feeders, which arrangement would prevent the possible re-occurrence of arcing between feeders.

The line arresters had, however, in the meantime been carefully watched, and after every storm the telltale papers were collected and found to be perforated with a greater or less number of small holes, each hole being slightly discolored around the edges.

The sensitiveness of these condenser arresters was particularly noticeable, in that the telltale papers were found to be punctured at the slightest provocation, when, in fact, no considerable thunder storm had passed over the lines; and yet, sensitive as they were to slight charges on the line, it is remarkable to note that the simple carbon spark gaps belonging to the local company, which have already been mentioned, and which provided a gap $\frac{1}{8}$ inch between electrodes, frequently received discharges in preference to the minute spark gap of a neighboring condenser line arrester. Such occurrences, coupled with many others of a similar nature, point to the existence of nodal points and the necessity of distributing line arresters at frequent intervals over the system.

In fact a lightning arrester connected directly to the terminals of a generator or motor offers no absolute guarantee of protection to this particular piece of apparatus. The presence of the arrester simply offers an opportunity for discharge. The discharge may occur in the armature or it may occur through the arrester, according to the particular conditions existing at the time of each discharge. The arrester could have a comparatively large spark gap, and the breaking down strain of the armature insulation be low, and still the discharge might prefer the large gap to the weaker insulation; while, on the other hand, the arrester could have a very small spark gap and the armature be provided with the highest grade of insulation, yet in some cases this insulation would be pierced by the discharge in preference to the small spark gap of the neighboring arrester. A striking example of this possibility is illustrated in Figure 24. A is a type of strain-wire insulator which is ordinarily capable of withstanding from 15,000 to 20,000 volts. B shows a wire connecting an overhead return to the ground wire return. The distance between wire B and the iron hoop holding the strain wire is about one inch. During a violent thunder storm the insulator A was punctured by a discharge which passed from the trolley wire through the insulator to the iron hoop and thence across the one inch air space to the grounded wire B, and this very high ohmic resistance path was taken in preference to a neighboring line arrester having a small spark gap. Had an arrester been connected at this point there is no question but that the arrester would have taken the discharge; but by reason of the nodal points which are formed along the line by the electric surgings, a

lightning arrester 100 yards away, although it is liable to take a large proportion of the discharges, does not by any means offer an absolute guarantee of protection to a neighboring piece of apparatus. A large number of line arresters, that is, a large number of opportunities for discharge, is the surest means of securing efficient protection.

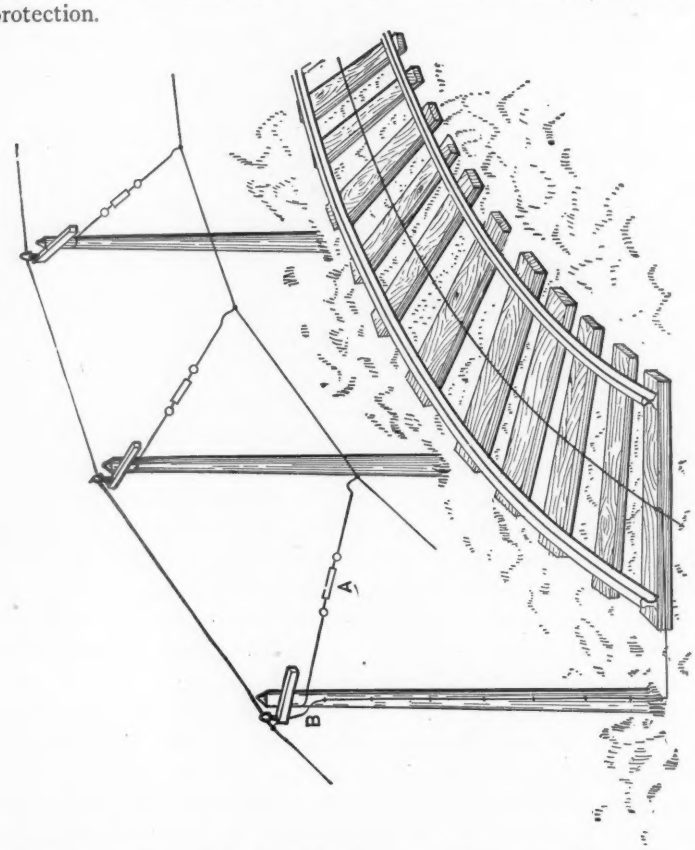


FIG. 24.

The results obtained with these condenser arresters have exceeded my expectations, and in my opinion have thrown considerable light on the intensity and volume of discharges commonly found in electric light and power circuits. During my two months' stay in Denver not a single condenser was disabled, nor were any of the telltale papers burned. I was not present in Denver after

the burned out spark gaps in the station had been replaced, and am therefore not in possession of any further data from that source. But in Colorado Springs, where I spent the next following six weeks, I connected three of these condenser arresters in the station of the Colorado Springs Rapid Transit Railway Company, and was treated to many violent thunder storms, through all of which these arresters showed a wonderful capacity for repeatedly and rapidly discharging the line. Through many of these storms the discharges passed the spark gaps as many as twenty times a minute, completely riddling the telltale papers.

I may, therefore, say with emphasis that the condenser lightning arrester has proved itself most efficient in points of sensitiveness, durability, and general reliability. In actual service it has demonstrated the successful construction of a truly discriminating direct current lightning arrester.

The Non-Arcing Railway Lightning Arrester. — I have, however, designed a lightning arrester which is much smaller, cheaper, and, perhaps, in every way more desirable than the condenser arrester. It is also a discriminating lightning arrester.

I had frequently noticed what is probably familiar to many of you, namely, that a disruptive discharge will leap over a non-conducting surface much more readily than through an equal air space. The non-conducting surface seems to form an entering wedge, as it were, through the air, so that this being already partly split or ruptured the discharge has but to further separate the air from the non-conducting surface instead of boring its own path through it. A pencil mark over a rough piece of glass or unpolished marble still further reduces the breaking down strain.

But to avail myself of this fact in the construction of a lightning arrester was a problem over which I pondered for some time. My design was to bring electrodes located in a discharge surface near enough together to form a lightning arrester spark gap, and at the same time to avoid the passage of dynamo current when the electrodes were connected to the terminals of a 500-volt direct current generator. I reasoned that a dynamo arc to be maintained must be fed by the vapors of its electrodes. To prevent an arc, the formation of such vapors must be suppressed. My first attempt in this direction proved successful. I drew a pencil mark about two inches long over an unpolished piece of marble, covered this

with a second piece similar to the first, and, having previously slipped between the two marbles pieces of aluminum foil as terminals to the pencil mark, I bound the whole together with twine. These terminals were now connected to the terminals of a 500-volt direct current generator and disruptive discharges caused to pass between the marbles and over the pencil mark. A one-ampere fuse was connected in the dynamo circuit. No current following these discharges, the terminal foils were brought successively nearer together, testing each time for the passage of dynamo current. When

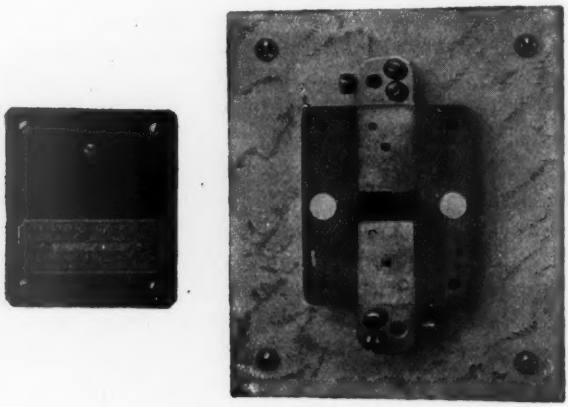


FIG. 25.

the electrodes had reached a distance of a quarter of an inch from each other the fuse was blown. The terminals were now placed a half-inch apart, and oft-repeated tests failed to establish a short circuit. The dynamo was now cut out, and upon resting my hand on the upper marble, while the discharges were still passing, I noticed a considerable mechanical shock, and when the twine was removed the upper block was thrown off. In consequence of this, it seemed advisable to provide more space for the discharge. A small groove was, therefore, cut in the lower marble from one electrode to the other, and well blackened with a lead pencil mark. Discharges now failed to produce the above mentioned mechanical shock or to throw off the cover. It was, however, noticed that after several discharges had passed this pencil mark disappeared, having been dis-

sipated and apparently scattered over the surfaces of the two marbles. To overcome this difficulty a piece of wood was laid into the lower marble between the electrodes, and into this a shallow groove was burned. This construction, which is shown in Figure 30, seemed to possess some advantages over the one already described — it suggested more lasting qualities. Various materials were now tested into which one or more discharge grooves might be burned, such as fiber, felt, leather, ivory, boxwood, celluloid, and others, but most of these proved unsatisfactory for various reasons. With fiber, the charred surface was quickly worn away; ivory chipped off in small pieces; both leather and felt crumbled away. Lignum-vitæ, however, proved to be a most excellent material. In the final form adopted for this arrester both upper and lower blocks were made of this material, thus enabling the discharge grooves to be burned into the lower block itself, and avoiding the necessity of inserting a discharge piece between the metal electrodes. This arrester for station use is illustrated in Figure 25; for line use in Figure 26. The blocks are 3 inches wide by $3\frac{1}{2}$ inches long and 1 inch thick. Two brass electrodes each 1 inch wide are laid into the lower block, flush with its surface, the distance between electrodes being $\frac{1}{2}$ inch. The charred grooves are nine in number, and about $\frac{1}{16}$ inch wide by $\frac{1}{32}$ inch deep.

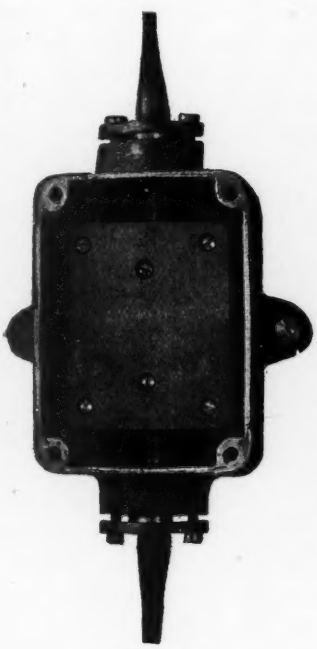


FIG. 26.

Another and more simple form of this arrester was also constructed. A hole was bored through a solid block of marble, the center of which was then filled with a cylindrical block of hard maple having grooves burned in on the sides. Solid brass cylindrical electrodes were then inserted in either end, making a snug fit. But in practice these marbles were in many cases split open by the expansive force of the discharge, thus demonstrating the necessity of the vent

which is obtained by clamping two surfaces together, and between which the discharges may pass.

This device, like the condenser arrester, constitutes a strictly discriminating lightning arrester. In regard to its action I have been asked why a discharge should find an easier passage across a conducting film than through a non-inductive conductor having the same ohmic resistance as the conducting film. My conception of the case is as follows: When a discharge passes through a conductor of more or less ohmic resistance the time of discharge is considerable; there is a great strain from all parts of the charged surfaces during the time of passage; and there will be a tendency to discharge or "side flash" along paths normal to the conductor. The passage of the discharge

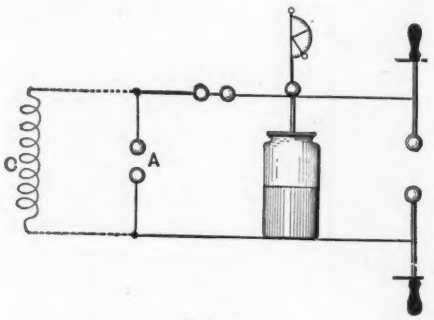


FIG. 27.

may be likened to the passage of tangible matter through a dense fluid — there is a gradual yielding of the opposing resistance, but nothing is broken. When, however, a discharge passes over a conducting film as described, there is a sudden breaking down or giving way of the dielectric, and this is aided by the presence of the conducting film. The film, however, does not act in the sense of what is commonly called an electric conductor, but as a wedge, splitting the dielectric preparatory to the passage of the disruptive discharge.

The difference between these two cases is very clearly illustrated by the discharge of a Leyden jar provided with a pith ball electrometer. Take the arrangement shown in Figure 27; while the machine is charging the battery of jars the increasing charge can be observed by the deflection of the pith ball, until finally a disruptive discharge takes place across the arrester or spark gap A, and the pith

ball is seen to fall back suddenly, indicating in this manner complete discharge. If, however, the gap A be removed and the discharge be caused to pass either through the inductive coil C, or in its stead a non-inductive high ohmic resistance, the pith ball at the moment of discharge will fall part way only, indicating thereby an incomplete discharge. The sound of the discharge in the latter case is also very different from that in the former — it is more like a thud, suggesting opposition to the passage, whereas in the former case the sound is that of a crack, indicating something instantaneous and complete.

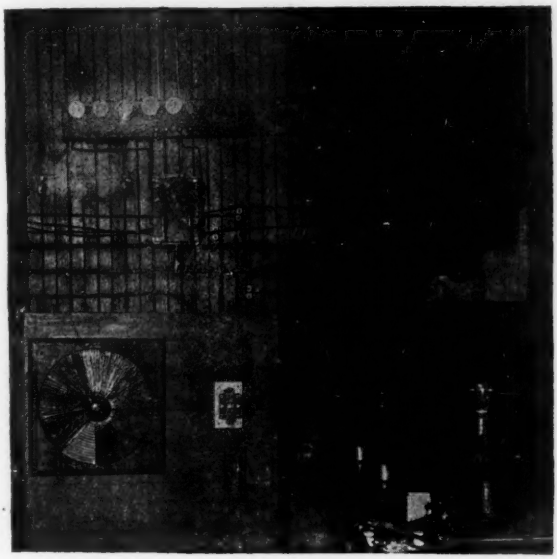


FIG. 28.

The non-arcing property of the arrester is easily understood; the conducting vapors which are necessary to the formation and maintenance of a dynamo arc are suppressed by the cover, which fits tightly over the metal electrodes. In Figure 28 the arrester is seen in operation. The terminals of the arrester are connected to the terminals of a 500-volt direct current generator. The cover is of glass so that the discharges may be seen. In the upper part of the figure, five 100-volt lamps in series indicate the dynamo pressure; just below this and to the left is a long horizontal 5-ampere fuse; to the left of the arrester

is a spiral choke coil connected in the dynamo circuit and interposed between the arrester and the generator. This coil is very similar to those which I used in my Colorado experiments. The disruptive discharges immediately below the arrester represent the means used for suddenly charging the dynamo circuit. The discharges across the arrester are distinctly seen through the glass cover. When, however, this cover is removed, the first discharge establishes a short circuit and the fuse is instantly blown, as seen in Figure 29.

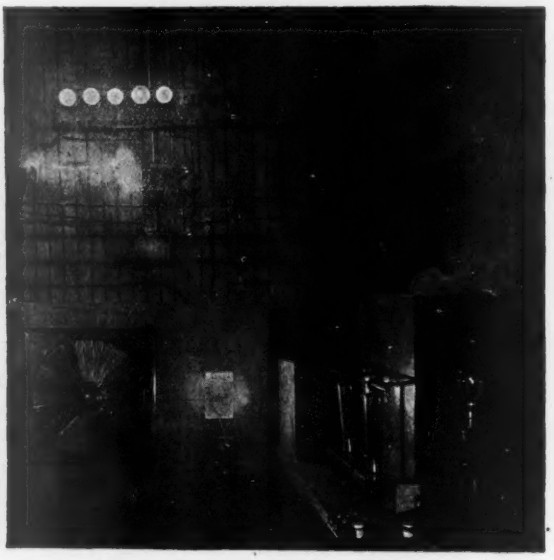


FIG. 29.

The relative ease with which a discharge will leap over such a surface in preference to a few turns of large copper wire is illustrated in Figure 30, which is taken from a photograph. Figure 31 shows the arrangement of the apparatus more clearly. A is an arrester such as I have been describing, and is provided with a clear glass cover so that the discharges may be seen. C is a choke coil connected in parallel to A; it is 16 inches in diameter and has seventeen turns of No. 0 copper wire. Discharges from a battery of Leyden jars invariably pass at A in preference to the path C, as shown in the photograph.

A thorough test of these arresters has been made in both Denver and Colorado Springs during the past summer. Figure 32 represents the equipment used in Denver. There were ten feeders, each feeder

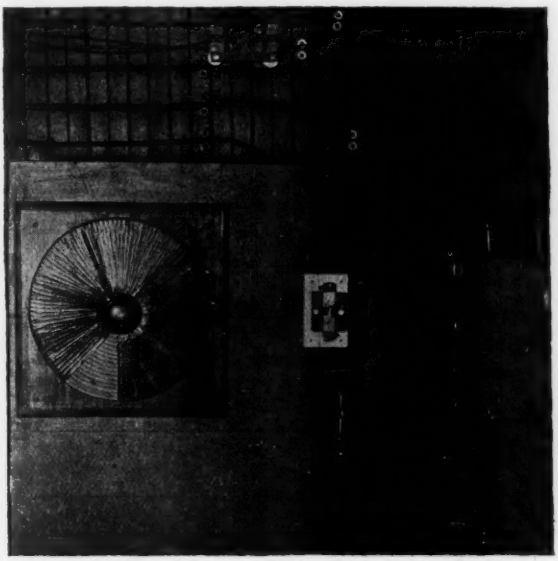


FIG. 30.

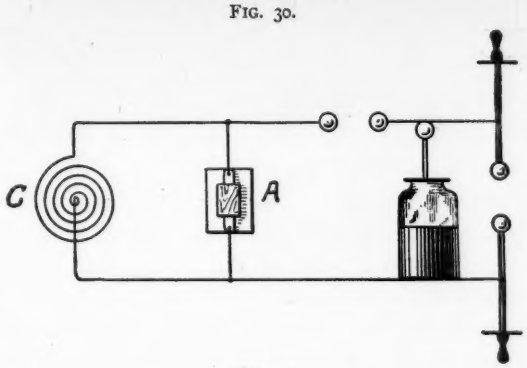


FIG. 31.

being provided with three arresters placed three feet apart. These are indicated at 1, 2, and 3. The object of using three arresters to each feeder was to avoid nodal points. s represents the circuit-break-

ers; T is a tank arrester; S 1 the discharge circuits of the tank arrester; and 4 represents spark gaps in these discharge circuits. None of the arresters were provided with telltale papers, and although they were carefully watched during thunder storms no indications were observed of passing discharges. After the first storm following their installation the writer removed the covers of the upper ten, and of these six showed marks of discharge; the remaining twenty were constructed on the "solid marble" pattern, and were consequently difficult

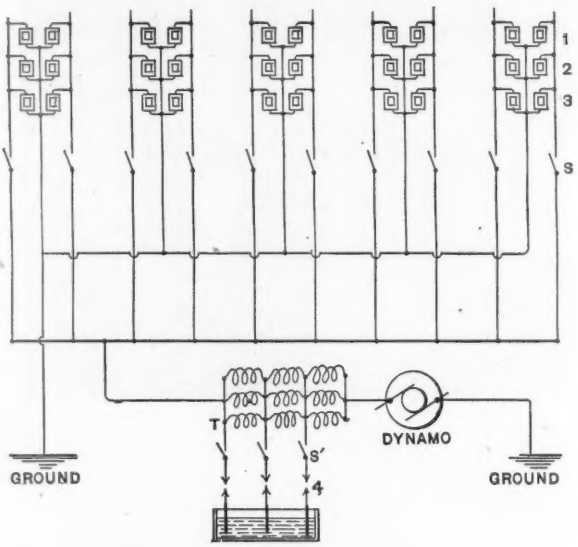


FIG. 32.

and unsatisfactory to inspect. One of the upper ten arresters was subsequently dismounted and photographed, and of this Figure 33 is an excellent copy, clearly showing the smudge formed by the discharge over the marble surfaces.

The only mishap which occurred to any of these arresters was the explosion of one of the "solid marble" type. No experimental line arresters of this type were used on the Denver plant. In Colorado Springs, however, twenty-five were installed on the line and twenty-four in the station. Some of these were of the divided kind (see Figure 25), others of the solid marble pattern. Nearly all of the latter

were split open by the discharges, while of the former none was damaged in the slightest degree. One of the line arresters was provided with three connections to one feeder, with a spark gap and telltale

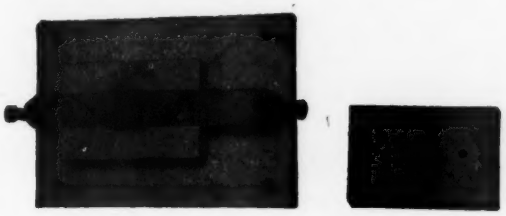


FIG. 33.

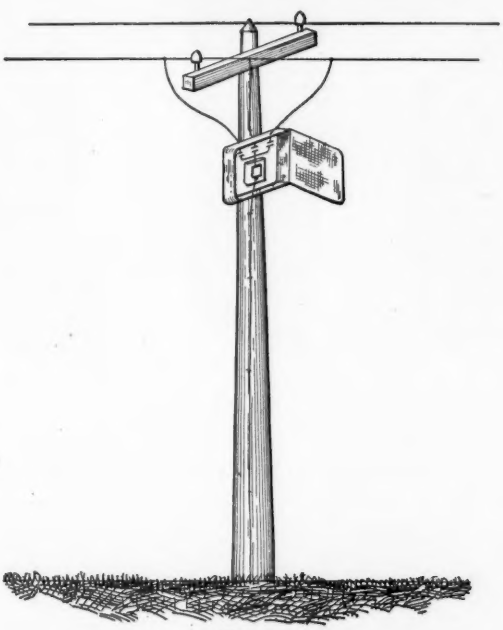


FIG. 34.

paper in each discharge circuit. This arrangement is shown in Figure 34. The connections to the feeder were made about two feet apart. After thunder storms each telltale paper was found to be perforated, but whether the discharges occurred simultaneously or

successively is not known. The perforations shown in Figure 35 were taken from this arrester.

This non-arcing railway lightning arrester is eminently suited for the protection of direct current circuits up to 1,000 volts. On 1,000-volt alternating current circuits from smooth body armatures it also operates satisfactorily, but on similar circuits from toothed body armatures the arresters break down after a few discharges, and a short circuit is established. However, it is not impossible that two or three of these arresters might be used to good advantage in series on circuits of high potential.

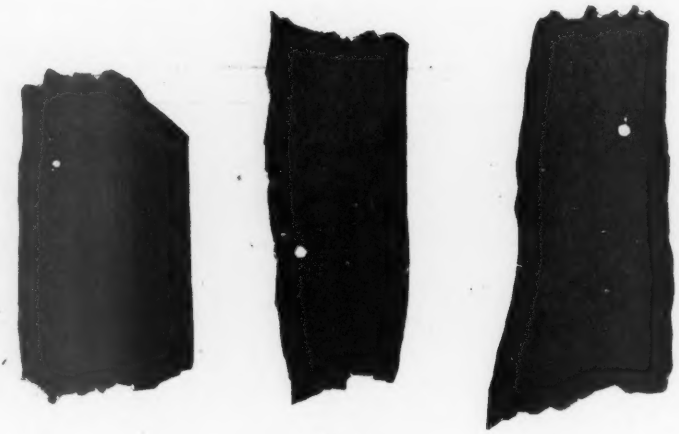


FIG. 35.

The especial advantages of this arrester may now be summed up as follows:

1. It offers a direct and non-inductive path to earth.
2. It is absolutely non-arcing, and consequently requires no attention after being once properly installed.
3. It has no moving parts and there is nothing about it to get out of order.
4. It is small, and therefore easily installed under a car.
5. It is cheap, and can therefore be used in large numbers on the line, on the cars, and in the station.
6. Its non-arcing property avoids danger from fire, which property

also insures the non-interruption of the system due to blowing of fuses and constant throwing of the circuit-breakers.

7. Its simplicity and reliability will commend it to every one.

In my closing remarks I wish to answer the now old and oft-repeated question, "How many and what kind of arresters would you advise us to use on our line?" as follows: The proper number of line arresters is that number which will prevent discharges from entering the station. Station arresters, if used at all, should be installed with the one idea of providing a final opportunity for discharge; but, as the tendency to discharge occurs on the line, often several miles away from the station, a sufficient opportunity should be provided *there* where the tendency to discharge originates, and in this manner advantage may be taken of the large inductive resistance afforded by the circuits leading back to the station. If discharges enter the station it is a sure indication that they have done so for lack of sufficient opportunity to discharge from the line — for lack of a sufficient number of line arresters.

It is well to protect dynamos with lightning arresters. It is better to avoid the necessity of this protection by discharging the line.

It is even well to use a lightning arrester having a circuit interrupting attachment. It is better to avoid the necessity of a circuit interrupting attachment by using a non-arcing arrester. In fact, an ounce of prevention is always better than a pound of cure.

SMOKE PREVENTION.

By HENRY J. WILLIAMS, A.B.

Read May 10, 1894.

In dealing with the interesting problem of smoke prevention, which claims our attention this evening, the short time at my disposal will only permit me to indicate very briefly in what directions attempts have been made for securing this desirable end, show what progress has been made, and point out how far the solution of the problem is possible and how far impossible.

Smoke is almost invariably produced wherever bituminous coal is largely used, for its complete combustion is rarely realized.

Anthracite coal and coke are flameless fuels, and do not produce smoke; while gas, which is only used at present in rare cases, is an ideal fuel, for when properly mixed with air it can be burned without causing any smoke. For manufacturing purposes, however, nearly all these smokeless fuels are out of reach, owing to their high cost.

The most flagrant examples of the smoke nuisance are to be found in Western cities, notably Pittsburg, the great "Smoke Producer," Cincinnati, Cleveland, Chicago, and St. Louis, where the efforts of Smoke Commissions have for some years been directed towards studying and abating the evil. We can learn a great deal from the experience of these cities.

A large part of the smoke is directly traceable to domestic fires, where the combustion is generally conducted in a very slovenly manner. The methods of preventing this smoke from domestic bituminous coal fires have, unfortunately, not been sufficiently studied, and the only remedies that suggest themselves are to use coke or anthracite coal. Although gas is still comparatively expensive for this purpose, the question might advantageously be looked into, whether gas, the consumption of which can be closely regulated and which can be

extinguished when not wanted, would not, when burned in an improved form of fireplace or stove, even at present prices, prove very nearly as economical for heating dwellings as the ill-managed coal fires which are kept burning all the time, and which yield in open grates, at best, only about 7 per cent. of the heating power of the coal.

Without stopping to consider the metallurgical and other operations which are compelled to use smoky fires so as not to oxidize or destroy their products, the great bulk of the smoke is caused by the numerous boiler fires and power plants, for both have to contend with the ignorance of firemen whose only care appears to be to keep up the requisite amount of steam, regardless of consequences.

The coals used for steaming purposes usually carry from 20 to 35 per cent. of volatile matter. To put it very briefly:

This volatile matter consists of combined water and lighter hydrocarbons of the character of marsh gas, which will burn without smoke, together with a whole series of simple and complex heavy hydrocarbons, which are more troublesome. At a red heat dissociation readily occurs, carbon is set free, and a reaction something like the following takes place: $C_2H_4 = CH_4 + C$.

It is this separated carbon which is the cause of what we call smoke, for unless the products of combustion are kept at a very high temperature, probably not far from 2000° F., and are thoroughly mixed with an abundance of heated air, the carbon will be carried along by the rapid draught, and will pass out unchanged as visible smoke.

Now the conditions necessary for complete combustion are scarcely ever realized in ordinary hand-firing of boilers; on the contrary, they are more nearly as follows: First, the furnace doors are opened every fifteen or twenty minutes for charging, and torrents of cold air rush in and cool the products of combustion; second, the cold fuel reduces the temperature of the hot bed of coals, and, moreover, requires time to reach the degree of heat of the furnace; third, the volatile matter, moisture, and combined water, the latter amounting in some cases to 15 or 20 per cent., as they escape in the form of gases or vapor, absorb and carry off a considerable amount of heat; fourth, when air first strikes the fuel it forms more or less carbonic dioxide, and when a large portion of this becomes reduced to carbonic oxide by the glowing fuel it too absorbs heat during this reduction, only a part of which is recovered during the combustion which follows; fifth, above the

now comparatively cool fuel bed we have an escape of combustible gases, as they are distilled from the coal, but unfortunately these are mixed with the large amounts of nitrogen and carbonic dioxide which come off at the same time. The latter act like a blanket, and do their best to prevent the combustible gases from uniting with the oxygen of the draught. If these gases accidentally become *cooled below a certain point*, we may have what would otherwise seem to be impossible, viz.: Combustible gases existing side by side with free oxygen *without combining*. And so we see that combustion, which ordinarily appears to be a simple matter, is a very complex one when it takes place under a boiler.

Furthermore, if the air of the draught, which contains but one volume of free oxygen to four volumes of inert nitrogen, has to pass through a thick bed of glowing coal before mixing with the combustible gases which are escaping above the fire, it will practically have been deprived of the whole of this free oxygen without which the combustion of these gases is impossible. More or less draught above the fire is, therefore, necessary, unless the fire is very thin, and it must be obvious to all that this draught should be highly heated to be able to lessen the smoke by the combustion of the separated carbon which causes it.

There is a current notion that abundant smoke means the loss of a large amount of fuel. In reality this loss is so small as to be insignificant. Experiments conducted for many hours have been made where the smoke was carefully filtered or washed, and the collected carbon weighed. The extreme limits of loss, with very smoky fires, lie between $\frac{1}{3}$ and $\frac{1}{2}$ of 1 per cent., which represents only from 6.7 to 10 pounds of carbon lost per ton of coal used.

The all important requirements for a wholly successful smoke preventing device appear to be:

1. Efficiency. 2. Capacity. 3. General Applicability.

1. — EFFICIENCY.

This includes: First, the development of a *high* temperature combined with oxidizing action, so as to insure the combustion of the separated carbon; second, regularity of action under varying conditions, such as charging fresh coal, cleaning fires, inattention of firemen, etc.; third, the device should not be liable to get out of order

under ordinary conditions of use; fourth, there should be little, if any, increase in the cost of operating.

2. — CAPACITY.

The capacity should be such that efficient action will be secured, not only when the boiler is working up to its full rated capacity, but even when forced in order to meet extraordinary demands.

3. — GENERAL APPLICABILITY.

This includes: First, ready adjustment to all forms of boilers and boiler settings; second, comparatively low first cost; third, repairs small in number, easily made, and at small cost; fourth, application where space is already limited; fifth, operation without injury to boilers or other accessories.

There are devices without number that have been proposed for remedying the smoke nuisance, many of which totally disregard the fundamental principles of combustion. Among the better ones there are few indeed that are not capable of doing all that they claim under *special* conditions; but the severe and all important test which few are able to pass is that of capacity.

In St. Louis some furnaces, which burn only from eighteen to twenty pounds of fuel per square foot of grate area per hour, are capable, when provided with the better devices, of showing good smoke records. As a general rule, however, this fuel consumption is greatly exceeded during the greater part of the time of their operation, and it is not at all uncommon to find boilers forced to the extent of burning thirty pounds of coal per square foot of grate per hour. It is almost needless to point out that this very general overtaxing of the boilers, which also prevails in the majority of our Eastern factories, is accountable for the greater part of the trouble, and a long stride towards reducing the smoke can be made by simply increasing the capacity of the boiler plants.

Smoke preventing devices generally reduce the capacity of the boilers; for example, in Chicago, where conditions somewhat similar to those mentioned prevail, the results of thirty-nine careful tests with smoke preventing furnaces on an average showed only 74 per cent. of the capacity of the ordinary furnaces in burning coal, while they

reduced the work of the boilers 28 per cent., and required about 2 per cent. more coal to do the same work.

Finally it may be stated, without fear of successful contradiction, that not one of the devices so far brought forward is capable, in its present form and application, of *fully* meeting and satisfying *all* the requirements stated above.

The problem of complete smoke prevention where the fuel is applied directly remains, therefore, still unsolved to-day; but a great deal has been done in the way of controlling and mitigating the evil, and I shall now give a brief outline of the more important systems that have been proposed with this object in view. They are nowhere better stated than in the reports of the St. Louis Smoke Commission, where they have been classified under seven heads.

1. Steam Jets. 2. Firebrick Arches or Checker Work. 3. Hollow Walls for Preheating Air. 4. Coking Arches or Chambers. 5. Double Combustion. 6. Downward Draught Furnaces. 7. Automatic Stokers.

1. — STEAM JETS.

These may be placed in a variety of positions, above or below the fire, in the side walls, or even in the bridge wall, the object being to hasten combustion by promoting the mixture of combustible gases with hot air. Where the heat is high and the charging of the coal is moderate and regular, they yield fairly satisfactory results; but where the firing is careless and too much coal is put in the temperature is lowered, and the action of the jets tends to retard rather than to promote combustion. The jets must also be carefully adjusted to the varying requirements which are made upon the boilers, a thing which with ordinary firemen is never attended to properly, and they are apt to cause injury by exercising a blowpipe action upon the boiler shell. With ample boiler capacity and not too variable service, and with skillful and reliable firemen, steam jets can be made to yield satisfactory results, but not without some increase in the cost of operating.

2. — FIREBRICK ARCHES AND CHECKER WORK.

These may be placed near the rear end of the fireplace or over the bridge wall. They cause the smoke, gases, and air to pass through a constricted passage close to the fire bed, and serve not only to reflect the heat, but as strong accumulators of heat which tend to main-

tain a uniformly higher temperature. The checker work serves the same object in a different way by dividing up the general volume of smoke and gases into a number of small currents. With careful firing both of these appliances can be made to yield good results, but only to a limited extent, and another and more serious objection is their want of durability and consequent high cost for repairs, accompanied by frequent interference with regular operation.

3. — HOLLOW WALLS FOR PREHEATING AIR.

A number of patents have been taken out based upon the system of providing hollow walls for preheating the air of the draught; but the latter generally fall short of the requirements, owing to their lack of capacity and tendency to become clogged.

4. — COKING ARCHES OR CHAMBERS. 5. — DOUBLE COMBUSTION.

The same may be said of coking arches or chambers, for these lack durability, owing to the fluxing action of the ash combined with exposure to very high temperatures; while the double combustion furnaces which have two fireplaces alternately fed, the hot gases of one passing over or through the other, labor under the disadvantage that large volumes of useless gases pass through the fires and carry off by absorption large amounts of heat.

6. — DOWNWARD DRAUGHT FURNACES.

This system seems more promising. The fuel is charged on top, as usual, but the air and gases are made to pass downward through the glowing bed of coals, thereby becoming heated and bringing about a more perfect combustion. The grate bars are generally hollow tubes filled with water, which are connected with a water-leg and made part of the boiler system. They require to be set a little further apart than ordinary grate bars, but where caking coal is used little fuel drops through. Sometimes an auxiliary common grate is placed below to catch these coals, air being admitted below this grate to complete the combustion. This system is well adapted to insure a good smoke record, and has the advantage of being readily attached to a variety of boilers; but it is liable to defects of construction, the water tubes may be subjected to unusual strains at the joints, and the latter are

not wholly reliable. The system, however, gives great promise for the future and is well worth the study required to secure the needed improvements.[1]

7. — AUTOMATIC STOKERS.

Finally we have an innumerable number of devices for supplying coal to the fire bed continuously, in place of the irregular and unreliable service of the ordinary fireman. The fuel is introduced in a great variety of ways, but as a general rule it is delivered from a hopper above or in front of the fire bed, over a fixed or inclined grate or a movable inclined step grate. The grate bars are made to move automatically, one or more at a time, with a sort of rocking motion which slowly and continuously pushes the coal forward as it drops over the steps of the grate. Time is thus allowed for the coal to heat gradually and to go through the coking process, the volatile matter, meanwhile, having to pass over the highly heated bed of glowing coal, which is not intermittently cooled by additions of cold fuel. By the time that the fuel reaches the end of the grate nothing but clinkers and ashes should fall over into the ash pit. With such a system of continuous firing many of the disadvantages arising from the cooling of the products of combustion in the ordinary system of hand-firing are avoided, and it may fairly be said that many of the most efficient smoke reducing devices are to be found among the better grades of mechanical stokers. But for all that the success of mechanical stokers in preventing smoke *must not be overrated*, for they have serious limitations and may, in some cases, prove to be wholly ineffective.

To work well the coal must be properly sized, for they cannot be successfully run with lump coal or the "run of the mine;" they cannot be used at all with caking or clinkering coals, as the grate bars become choked and their action is impeded. The author has seen Roney stokers, which worked beautifully with Pittsburg steaming coal, or with any other high grade coals such as are used throughout New England, but which were remarkably *irregular* in their action

[1] Great improvements in this furnace have recently been made. The under grate also now consists of a set of water tubes connected by elbows with upright tubes screwed directly into the water-leg under the boiler. The hot gases, as they burn, are made to pass between these vertical tubes, which materially add to the heating surface of the boiler and greatly improve the circulation of the water. The cooling of the gases which escape from the coal appears to be prevented, and the smoke production is, therefore, greatly reduced.

when run with the ordinary grades of Illinois coal, carrying from 17 to 18 per cent. ash, which are used in St. Louis. Clinkers weighing over 100 pounds were not an infrequent thing, one of which, in the author's presence, required three quarters of an hour to take out. It is not an easy matter to remove such clinkers from an inclined step grate, and the fireman is all too apt to neglect doing the work thoroughly. When they are of frequent occurrence the life of the grate bars is brief and their cost foots up to a considerable sum, while the delays which are occasioned may be fatal to the use of mechanical stokers. Another serious objection is that mechanical stokers do not respond quickly to increased demands made upon them. In a power house for a street railway the boilers may, in the short space of fifteen or twenty minutes, be called upon to double or treble the amount of work that they have been doing, owing to sudden increases in the amount of travel, which cannot always be foreseen. There are few mechanical stokers that can respond to such demands in less than three quarters of an hour, in spite of the devices with which they are provided for regulating their speed.

Where the boiler capacity is ample and where uniform steam pressure is required, also where the fuel is of good quality, mechanical stokers are very satisfactory and can be run with a minimum production of smoke; but *just as soon as they are driven beyond their capacity*, and the same may be said of *all* other smoke preventing devices, without exception, the furnaces *return to their evil ways*, and the torrents of black smoke which issue from their stacks would fully justify the name of "smoke producers" instead of "smoke preventers."

One thing more before leaving this subject. Mechanical stokers require to be run with more or less intelligence, or they will be found to burn coal wastefully and prove to be expensive luxuries. A number of analyses of their flue gases which the author once made, out of curiosity, in St. Louis, in one of the large electric light and power plants, while examining the flue gases of a hand-fired boiler during a boiler test, revealed startling conditions which illustrate this point. An excess of air in the flue gases is no doubt necessary for good combustion and for the maintenance of a brisk fire, but this condition can be realized with about 25 per cent. excess air, anything above this merely serving to cool the products of combustion and representing, therefore, wasted fuel. The analyses revealed 75 per

cent. excess of air in the flue gases from a battery of six mechanical stokers, which at the time were in their normal condition of working and were not being driven. The company was no doubt much interested to learn that, under the prevailing condition of running, 50 per cent. of this air was continuously and to no purpose swelling the yearly coal bills.

The present aspect of the smoke problem is encouraging. The subject of combustion has been studied and is now better understood than it was, and while it still seems difficult to prevent smoke from bituminous coal fires altogether, unless we make use of fuel gas, yet the work of the various Smoke Commissions, and particularly those of Cincinnati and St. Louis, is bearing fruit, and compliance with the conditions which I have mentioned at present succeeds in abating about 75 per cent. of the smoke from boilers. In Chicago ordinances have been on the statute books for ten years, but they are ill enforced. Pittsburg has a smoke ordinance for the East End or residence portion of the city, but has done nothing towards abating the nuisance in the manufacturing districts, where the problem is very difficult to handle. In Cleveland nothing has been done except to agitate the question. In St. Louis the commission sees that the law is enforced, regularly makes boiler tests and trials of new smoke preventing devices, and assists manufacturers in every possible way in adopting the device which is best adapted to their needs.

Among a number of good devices which have come to the author's notice, one of the most efficient is the Standard Smokeless Furnace of St. Louis. This furnace combines the action of a mechanical stoker with an arrangement for coking the coal on a sort of coking plate before it is actually delivered to the step grate. It has been carefully tried by the commission and found very satisfactory. It increases the efficiency of the furnace from 10 to 20 per cent., maintains an excellent smoke record, and is capable of developing the full boiler capacity, but requires approximately half an hour's time to do so. It is readily adaptable to ordinary boilers, is moderate in cost, considering the saving in fuel realized, and is most efficient where the service is fairly regular or where at least half an hour's notice of an increased demand for steam can be given.

I have stated that the use of gas would solve the question of smoke prevention. Coal gas and water gas are out of the question for manufacturing purposes, owing to their high cost; but fuel gas,

which has been manufactured experimentally from Illinois coal at as low a cost as 8 cents per 1,000 cubic feet, appears at first sight to be within our reach.

This subject has been fully investigated in Pittsburg, and I will close this paper by presenting the figures which were there obtained, so that the present prospects of our being able to use gas for a fuel may appear.

One thousand cubic feet of the above mentioned gas has a calorific value of 243,391 heat units, which is equivalent to 5,053 heat units per pound of coal employed in making this gas, for 48.17 pounds of coal are required to make 1,000 cubic feet of gas. By direct calorimeter test the coal yielded 11,173 heat units, so that the efficiency of the gas from 1 pound of coal is 45.2 per cent.

Now 1 pound of coal by direct application shows a theoretical evaporation of 11.56 pounds of water, whence the gas from 1 pound of coal will theoretically evaporate 45.2 per cent. of 11.56, or 5.23 pounds of water.

Let efficiency in use of coal directly applied equal 50 per cent.

Let efficiency in use of gas directly applied equal 90 per cent.

Let cost of coal equal 6 cents per bushel,

and we have: 1 pound of coal with an efficiency of 50 per cent. will evaporate $\frac{50}{100}$ of 11.56, or 5.78 pounds of water; while the gas from 1 pound of coal with an efficiency of 90 per cent. will only evaporate $\frac{90}{100}$ of 5.23, or 4.71 pounds of water.

To evaporate 1,000 pounds of water we therefore require, with coal, $\frac{1000}{5.78}$, or 173 pounds of coal at 6 cents per bushel = 13 cents; with gas, $\frac{1000}{4.71}$, or 212.3 pounds of coal equivalent to 4,400 cubic feet of gas at 8 cents per 1,000 cubic feet = 35.2 cents.

It is therefore evident that with coal at 13 cents, and the calorific equivalent of this coal in the form of gas at 35.2 cents, the use of fuel gas, and consequently of the more costly illuminating and water gases, is out of the question.

I must also add that the above figures are even too favorable to the gas. Its price, 8 cents per 1,000 cubic feet, merely represents the cost of manufacture without any allowance for cost of distribution, which would double or treble the expense; also that the efficiency of gas taken at 90 per cent. is rarely realized under boilers, and would be nearer 60 or 70 per cent.

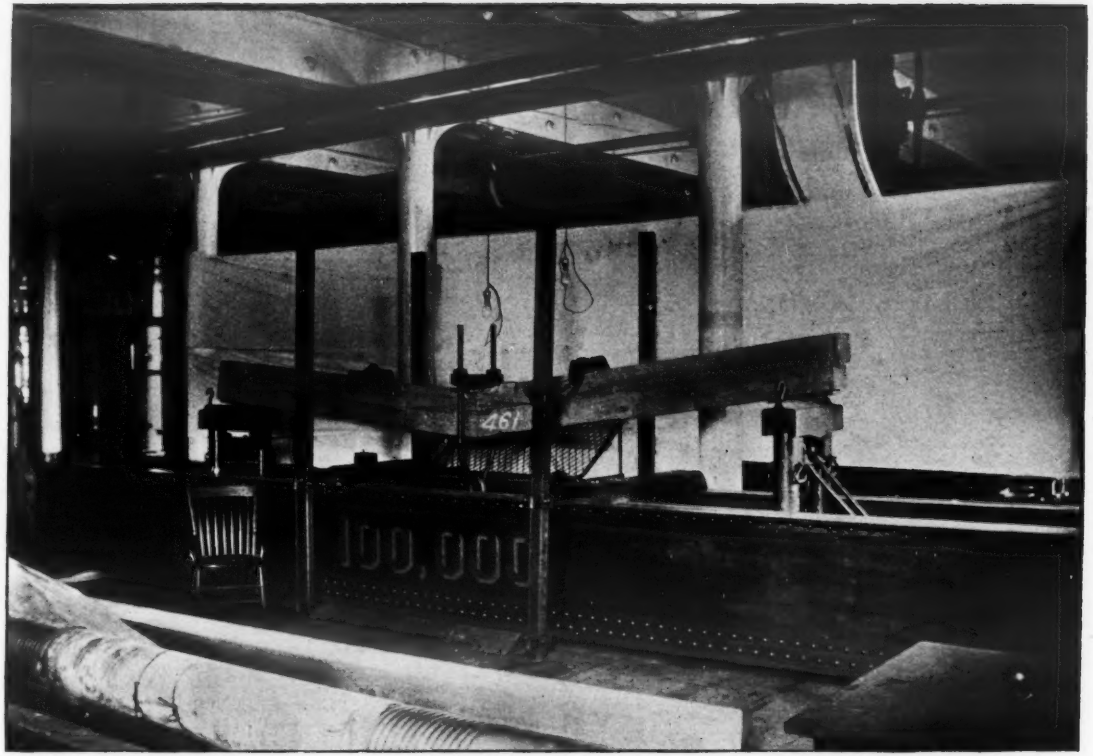
These figures would make the gas equivalent of coal cost more

nearly eight or ten times as much as coal, but the above figures are interesting as they show about the best results that we can expect to reach in the future, even with the cheap Illinois coals.

We must, therefore, for the present use coal, and if we burn it with all the skill that an intelligent study of the question dictates, there is no necessity for producing more than a moderate amount of smoke.

NOTE. — At the time that the above paper was read, a paper describing the Jones Under-Feed Mechanical Stoker was presented. This appliance has many excellent qualities to recommend it, and is in all respects true to the correct principles of combustion. The fresh coal is fed from below by means of a ram, and the combustible gases have to pass through about twenty inches of glowing coal, while the draught is maintained by means of a set of tuyere holes placed some distance below the surface of the glowing coals, the supply of air from which can be regulated. One great advantage appears to be that the fire can quickly be driven up to the full capacity of the boilers. If this device proves to be durable and to require few repairs, and is also of sufficiently low cost, it bids fair to be considered one of the best appliances yet proposed for insuring perfect combustion under boilers and for preventing smoke.

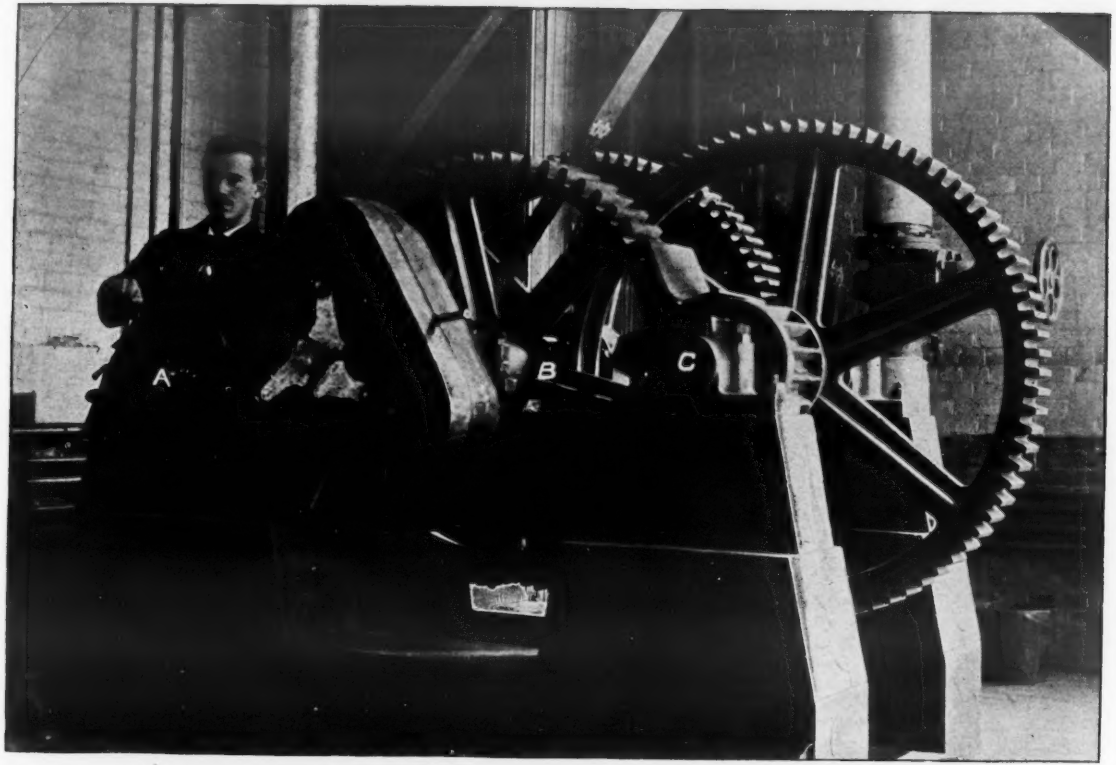
100,000-LB. BEAM MACHINE.



100,000-LB. BEAM MACHINE.

18,000-LB. BEAM MACHINE.

TORSION MACHINE — WEIGHING END.



TORSION MACHINE — TWISTING END.

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

I. APPLIED MECHANICS.

THE present paper is the first of a series in which it is proposed to publish such results of tests made as part of the regular work in the Engineering Laboratories of the Institute as may be of interest to the engineering public. Tests made in connection with thesis work will not be included.

The tension and compression tests of steel, wrought iron, and cast iron, together with the miscellaneous tests, were made in a 50,000-pound Olsen testing machine. The elastic limit and modulus of elasticity were calculated from micrometer readings of elongation taken on opposite sides of the specimen.

The tests on iron and copper wire were made on a rope testing machine up to December, 1892. Those in 1893 and 1894 were made in a machine constructed especially for wire testing. The modulus of elasticity and elastic limit were determined by measuring with a micrometer the extension in 100 inches.

The torsion tests were made in a special machine erected in the laboratory in August, 1893. The machine is capable of twisting off a 3-inch wrought-iron shaft 21 feet long. This apparatus, together with the measuring device and method of operation, was quite fully described in Vol. VI, No. 4, of the *Technology Quarterly*.

The rope tests were carried on in a testing machine built for that work. The machine requires a specimen about 10 feet long, and allows for a stretch of 4 feet. The capacity is 30,000 pounds. The eye splices by which the rope was held in the majority of cases were made by two sailors accustomed to splicing.

The beam tests up to 1892 were all made on a 50,000-pound transverse machine, 26 feet span. Of the tests in 1892–93, some were made on the 50,000-pound machine, and some on a smaller machine having

a capacity of 18,000 pounds in a 14 feet span. In the summer of 1893 the old wooden frame 50,000-pound machine was replaced by an iron machine of 100,000 pounds capacity, 26 feet span. The tests in the last half of 1893 and in the first half of 1894 were divided between the 100,000-pound machine and the 18,000-pound machine. In the 50,000 and 100,000 pound machines the load was applied by raising the ends of the beam by jack-screws and holding down at the center with a yoke attached to the weighing system. In the 18,000-pound machine the load was applied to the beam through one jack at the center, and the supporting force at one end was weighed.

The modulus of elasticity was obtained from deflections taken by micrometers at each side of the beam. The micrometers were attached to a frame fastened at the neutral axis in the center of the beam, and made contact with fine piano wires stretched, one on either side, over pins driven into the beam at the neutral axis, directly over the supports.

STEEL TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1887.											
Nov. 28	....	.4547	.2376	11.0	76,510	56,080	2.46	22.4	47.7	29,680,000	Bessemer, from Cambria Iron Works.
Dec. 12	.7606 dia.	.4543	.2210	11.0	74,841	53,900	2.43	22.1	51.0	29,178,000	Bessemer, from Cambria Iron Works.
Dec. 21	.7590 dia.	.4525	.2290	11.0	81,220	45,310	2.65	24.1	49.4	29,140,000	Bessemer, from Cambria Iron Works.
Dec. 21	.7642 dia.	.4587	.1710	11.0	54,940	....	2.92	26.5	62.6	29,730,000	Bessemer, from Cambria Iron Works.
Dec. 28	.7610 dia.	.4548	.2375	11.0	80,690	49,470	2.36	21.4	47.7	29,760,000	Bessemer, from Cambria Iron Works.
1888.											
Feb. 9	.7468 dia.	.4380	.1555	11.0	58,100	36,530	3.60	32.7	64.5	29,033,000	Bessemer, from Cambria Iron Works.
Feb. 21	.7500 dia.	.4417	.1735	11.0	56,930	39,610	3.13	28.4	60.7	30,882,000	Bessemer, from Cambria Iron Works.
March 15	.7390 dia.	.4289	.1550	11.0	59,220	38,470	3.10	28.2	63.0	30,397,000	Bessemer, from Cambria Iron Works.
March 19	1.01 x .506	.5110	.3745	4.005	81,283	44,026	.725	18.1	26.7	33,276,000	Section from I beam.
March 21	....	.7726	....	....	77,650	45,946	....	....	....	33,019,000	Cut from the compression side of I beam already strained.
March 22	.7620 dia.	.4560	.2290	11.0	81,500	51,533	2.42	22.0	49.8	29,046,000	Bessemer, from Cambria Iron Works.
March 26	.7497 dia.	.4414	.1590	11.0	57,200	37,378	2.97	27.0	64.0	29,432,000	Bessemer, from Cambria Iron Works.
March 29	.7500 dia.	.4418	.1735	11.0	56,130	....	2.50	23.0	60.0	26,940,000	Bessemer, from Cambria Iron Works.
April 9	.379 x 1.458	.5500	.2900	4.0	59.450	31,670	1.31	32.8	47.3	29,459,000	Nashua boiler plate.
April 13	.384 x 1.48	.5683	.2478	4.0	58,770	39,590	1.21	30.5	56.3	30,270,000	Nashua boiler plate.
April 13	.365 x 1.65	.6023	.3276	4.0	58,115	32,380	1.20	30.0	45.6	29,305,000	Nashua boiler plate.
Oct. 5	.7570 dia.	.4501	.2206	11.0	81,140	54,430	2.40	22.0	51.0	30,880,000	Bessemer, from Cambria Iron Works.
Oct. 10	.7670 dia.	.4620	.2290	11.0	79,640	55,190	2.41	21.9	50.4	29,300,000	Bessemer, from Hartman & Co.
Oct. 12	.7580 dia.	.4512	.2549	11.0	74,944	49,884	2.70	24.5	56.5	29,019,000	Bessemer, from Hartman & Co.
Oct. 19	.7590 dia.	.4530	.2290	11.0	80,470	54,150	2.20	20.0	49.4	28,393,000	Bessemer, from Hartman & Co.
Oct. 23	.369 x 1.49	.5498	.2645	10.0	61,657	37,284	1.79	17.9	51.9	30,135,000	Otis, for drums of new boilers, Mass. Inst. Technology.
Oct. 26	.398 x 1.511	.6014	.2544	10.0	54,370	30,760	2.04	20.4	58.0	28,608,000	Otis, boiler plate.
Nov. 5	.376 x 1.496	.5625	.2415	10.0	53,156	32,889	2.53	25.3	57.1	28,511,000	Otis, cut from plate used in Mass. Inst. Tech. boiler.
Nov. 13	.4095 x 1.3647	.5588	....	10.0	54,930	33,110	.875	8.7	....	29,826,000	Otis, cut from plate used in Mass. Inst. Tech. boiler.
Nov. 14	.375 x 1.494	.5603	.2324	10.0	55,173	29,451	2.38	23.8	58.5	28,849,000	Otis, cut from plate used in Mass. Inst. Tech. boiler.
Nov. 15	.3737 x 1.4974	.5596	.2616	10.0	54,220	31,270	2.31	23.1	52.5	27,490,000	Otis, cut from plate used in Mass. Inst. Tech. boiler.
Nov. 16	.7500 dia.	.4418	.2043	11.0	76,505	50,927	2.68	24.4	53.7	30,930,000	Bessemer, from Hartman & Co.
Nov. 23	.7560 dia.	.4480	.2210	11.0	82,420	54,687	2.52	22.9	50.7	28,740,000	Bessemer, from Hartman & Co.
Nov. 26	.7600 dia.	.4538	.2041	11.0	74,390	47,400	....	....	45.0	29,430,000	Bessemer, from Hartman & Co.
Dec. 3	.7650 dia.	.4596	.1963	11.0	73,750	48,952	2.77	25.2	57.3	29,740,000	Bessemer, from Hartman & Co.
Dec. 6	.7610 dia.	.4548	.2375	11.0	80,580	53,864	2.47	22.4	47.8	29,140,000	Bessemer, from Hartman & Co.
Dec. 11	.7680 dia.	.4632	.2124	11.0	78,900	52,900	2.57	23.3	54.1	27,770,000	Bessemer, from Hartman & Co.
Dec. 13	.7586 dia.	.4518	.2043	11.0	74,922	49,800	2.67	24.3	54.8	30,433,000	Bessemer, from Hartman & Co.
Dec. 18	.7630 dia.	.4572	.2123	11.0	80,040	....	2.55	23.2	53.5	28,700,000	Bessemer, from Cambria Iron Works.
Dec. 19	.7656 dia.	.4604	.2124	11.0	73,330	46,700	2.67	24.3	53.9	28,800,000	Bessemer, from Cambria Iron Works.
Dec. 31	.7546 dia.	.4465	.1960	11.0	80,560	50,400	2.61	23.7	56.0	30,591,000	Bessemer, from Cambria Iron Works.

STEEL TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1889.											
Feb. 11	.7550 dia.	.4477	.1963	11.0	78,850	48,023	2.52	22.9	56.2	30,521,000	Bessemer, from Cambria Iron Works.
Feb. 18	.4058 x 1.6013	.6498	.3429	4.0	57,710	....	1.02	25.5	47.0	.....	Otis boiler plate.
Feb. 19	.3768 x 1.821	.6862	.3128	4.0	55,670	....	1.34	33.5	53.8	.....	Otis boiler plate.
Feb. 26	.7550 dia.	.4477	.1885	11.0	81,240	52,250	2.13	23.9	57.8	30,240,000	Bessemer, from Cambria Iron Works.
March 7	.7610 dia.	.4548	.1979	11.0	78,710	45,070	2.78	25.3	56.5	29,768,000	Bessemer, from Cambria Iron Works.
March 8	.7560 dia.	.4489	.2043	11.0	80,196	50,120	2.61	23.7	54.3	30,322,000	Bessemer, from Cambria Iron Works.
March 10	.7607 dia.	.4543	.2376	11.0	81,560	49,520	2.36	21.4	47.8	30,580,000	Bessemer, from Cambria Iron Works.
March 12	.7550 dia.	.4477	.1886	11.0	80,860	50,257	2.57	23.4	57.9	29,337,000	Bessemer, from Cambria Iron Works.
March 19	.7510 dia.	.4430	.2043	11.0	80,570	48,540	2.51	22.8	54.0	30,100,000	Bessemer, from Cambria Iron Works.
March 23	.7530 dia.	.4453	.1963	11.0	76,120	46,036	2.50	22.7	55.9	31,120,000	Bessemer, from Cambria Iron Works.
March 26	.7568 dia.	.4498	.2043	11.0	79,475	45,573	2.13	19.3	54.5	29,642,000	Bessemer, from Cambria Iron Works.
April 3	.7550 dia.	.4477	.1963	11.0	80,980	50,260	2.50	22.7	56.1	31,035,000	Bessemer, from Cambria Iron Works.
April 5	.7550 dia.	.4477	.1964	11.0	79,850	48,020	2.48	22.5	56.1	29,781,000	Bessemer, from Cambria Iron Works.
April 11	.7570 dia.	.4500	.1970	11.0	80,200	50,000	2.53	23.0	56.3	28,400,000	Bessemer, from Cambria Iron Works.
Oct. 11	.3695 x 1.812	.6695	.2980	4.0	64,391	....	0.92	23.0	55.5	.....	Otis boiler plate.
Oct. 17	.378 x 1.041	.3917	.1872	2.0	59,614	....	0.93	46.0	52.7	.....	Nashua boiler plate.
Nov. 8	.405 x 1.237	.5010	.1957	3.0	58,146	....	....	....	61.0	.....	Nashua boiler plate.
Nov. 14	.7500 dia.	.4418	.1726	11.0	60,752	35,085	2.81	25.6	60.9	29,582,000	Bar, from Norway Iron Works.
Nov. 14	....	.4300	.1890	11.0	64,129	38,372	1.94	17.7	56.2	28,683,000	Bar, from Norway Iron Works.
Oct. 31	.7560 dia.	.4489	.1257	11.0	56,760	38,986	2.65	24.0	72.0	27,228,000	Bar, from Norway Iron Works.
Oct. 14	.7440 dia.	.4348	.1520	11.0	58,970	37,950	3.00	27.3	65 0	30,870,000	Bar, from Norway Iron Works.
Oct. 18	.7463 dia.	.4370	.1520	11.0	58,913	37,749	2 17	19.0	65 0	29,176,000	Bar, from Norway Iron Works.
Oct. 24	.7400 dia.	.4301	.1683	11.0	63,245	40,690	3.00	27.3	60.8	29,836,000	Bar, from Norway Iron Works.
Oct. 29	.7430 dia.	.4335	.1520	11.0	58,928	35,749	3.10	28.2	65.0	29,273,000	Bar, from Norway Iron Works.
Nov. 7	.7516 dia.	.4437	.1590	11.0	59,875	37,190	2.72	24.7	64.2	28,068,000	Bar, from Norway Iron Works.
Nov. 11	.7430 dia.	.4335	.1662	11.0	61,500	35,756	3.00	27.3	61.7	28,218,000	Bar, from Norway Iron Works.
Nov. 12	.7463 dia.	.4380	.1450	11.0	58,220	37,671	2.82	26.0	67.0	29,239,000	Bar, from Norway Iron Works.
Nov. 22	.7430 dia.	.4335	.1735	11.0	59,746	38,055	2.70	24.5	60.0	27,930,000	Bar, from Norway Iron Works.
Nov. 25	.7500 dia.	.4417	.1661	11.0	59,123	35,085	2.54	23.0	62.0	28,731,000	Bar, from Norway Iron Works.
Nov. 26	.7490 dia.	.4406	.1773	5.0	62,595	....	1.58	30.0	60.0	.....	Bar, from Norway Iron Works.
Dec. 9	.7420 dia.	.4324	.1660	11.0	60,870	35,840	2.80	25.5	61.6	32,475,000	Bar, from Norway Iron Works.
Dec. 10	.7400 dia.	.4300	.1520	11.0	61,244	36,040	2.93	26.6	64.6	29,798,000	Bar, from Norway Iron Works.
Dec. 11	.7380 dia.	.4277	.1661	11.0	61,900	36,300	3 02	27.4	61.2	27,300,000	Bar, from Norway Iron Works.
Dec. 13	.7460 dia.	.4371	.1452	11.0	58,159	37,749	2.93	27.0	67.0	28,490,000	Bar, from Norway Iron Works.
Dec. —	.7590 dia.	.4524	.1520	11.0	56,360	34,258	3.17	28 8	66.4	28,606,000	Bar, from Norway Iron Works.
Dec. 31	.7420 dia.	.4320	.1660	11.0	62,881	40,471	2.77	25.2	61.6	28,663,000	Bar, from Norway Iron Works.
Dec. 15	.7520 dia.	.4441	.1520	11.0	58,589	34,890	2.93	26.7	66.0	30,326,000	Bessemer.

STEEL TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1890.											
Jan. 2	.....	.4312	.1735	11.0	64,958	38,265	2.58	23.5	59.8	31,888,000	Bar, from Norway Iron Works.
Feb. 24	.7400 dia.	.4301	.1735	11.0	71,389	43,013	2.54	23.1	59.7	30,770,000	Bessemer, from McBarron & Co.
Feb. 26	.7295 dia.	.4178	.1757	11.0	74,150	44,272	2.65	24.9	58 0	30,524,000	Bessemer, from McBarron & Co.
March 3	.7400 dia.	.4300	.1660	11 0	59,291	29,070	2.75	25.0	61.4	29,804,000	Bessemer, from McBarron & Co.
March 6	.7422 dia.	.4327	.1772	11.0	68,180	45,071	2.63	24.0	59.0	29,470,000	Bessemer, from McBarron & Co.
March 11	.7479 dia.	.4394	.1724	11 0	69,410	42,100	2.80	25.5	60.0	28,008,000	Bessemer, from McBarron & Co.
March 12	.7428 dia.	.4333	.1735	11 0	59,260	28,845	2.35	21 3	60.0	30,460,000	Bessemer, from McBarron & Co.
March 18	.7590 dia.	.4524	.2124	11.0	69,060	38,674	2 58	23.5	53 0	24,555,000	Bessemer, from McBarron & Co.
March 25	.7508 dia.	.4427	.1195	11.0	50,147	19,200	3 25	30.0	73.0	28,397,000	Bessemer, from McBarron & Co.
March 26	.7426 dia.	.4332	.1964	11.0	70,983	40,397	2.50	22 7	54.7	29,139,000	Bessemer, from McBarron & Co.
April 1	.7481 dia.	.4394	.2042	11 0	57,760	33,000	1.88	17 0	53 5	28,885,000	Bessemer, from McBarron & Co.
April 2	.7463 dia.	.4374	.1799	11.0	58,408	28,575	2 78	25 3	58.9	32,799,000	Bessemer, from McBarron & Co.
April 8	.7285 dia.	.4168	.1452	11.0	62,761	34,787	2.88	26.1	65 2	32,135,000	Bessemer, from McBarron & Co.
April 11	.7476 dia.	.4390	.1229	11.0	50,505	19,364	3.41	31.0	72 5	29,479,000	Bessemer, from McBarron & Co.
April 15	.7442 dia.	.4347	.1320	11.0	51,230	19,550	3.16	28.6	69 7	30,653,000	Bessemer, from McBarron & Co.
Oct. 13	.7500 dia.	.4418	.1257	11 0	51,110	21,503	2.75	25 0	71.5	28,457,000	Bessemer, from McBarron & Co.
Oct. 14	.7500 dia.	.4418	.2206	11.0	51,518	21,503	2.03	18 5	50.1	27,665,000	Bessemer, from McBarron & Co.
Oct. 16	.7300 dia.	.4186	.1809	11.0	73,865	46,584	2.47	22.4	56.8	29,600,000	Bessemer, from McBarron & Co.
Oct. 17	.7500 dia.	.4418	....	11.0	....	....	....	....	....	29,292,000	Tool steel, from Fuller, Dana & Fitz.
Oct. 18	.7600 dia.	.4536	....	11.0	....	69,438	....	....	....	29,311,000	Tool steel. Unable to break with 50,000 actual load.
Oct. 20	.7500 dia.	.4418	.1194	11.0	50,294	26,029	3 09	28 1	27.0	28,055,000	Bessemer.
Oct. 22	.7600 dia.	.4536	.1963	11.0	64,169	47,395	3 77	34.3	56.7	29,392,000	Open hearth, from Fuller, Dana & Fitz.
Oct. 23	.7500 dia.	.4418	.1590	11.0	63,083	44,137	2.77	25.1	64.0	30,179,600	Open hearth.
Oct. 27	.7600 dia.	.4536	.1809	11.0	64,477	47,394	2.64	24.0	60 1	30,780,000	Open hearth.
Oct. 30	.7700 dia.	.4657	.1699	11 0	62,449	46,171	2.58	23.5	63.5	30,481,000	Open hearth.
Oct. 31	.7400 dia.	.4301	.2376	11.0	97,655	54,641	1.94	17.6	44.8	30,539,000	Bessemer.
Nov. 3	.7400 dia.	.4301	.2290	11.0	87,086	47,666	2.42	22.0	46.8	30,090,000	Bessemer.
Nov. 4	.7350 dia.	.4243	.2206	11.0	87,508	50,673	2.41	22.0	48.0	30,057,000	Bessemer.
Nov. 7	.7600 dia.	.4536	.1699	11 0	65,235	49,598	2.49	22.7	62.5	30,310,000	Bessemer.
Nov. 11	.7350 dia.	.4243	.2332	11.0	87,014	50,673	2.24	20 4	45 0	30,058,000	Bessemer.
Nov. 13	.7550 dia.	.4477	.1964	11.0	88,452	54,724	2.60	23 4	56.1	29,548,000	S. M. & Co. machine.
Nov. 14	.7550 dia.	.4477	.2507	11.0	92,514	61,424	2.25	20.5	44.0	29,784,000	S. M. & Co. machine.
Nov. 18	.7600 dia.	.4536	.2552	11.0	91,238	60,618	2.16	19 6	43 7	29,880,000	S. M. & Co. machine.
Nov. 20	.7500 dia.	.4418	.2642	11.0	93,706	62,244	2.33	21.2	40.2	30,180,000	S. M. & Co. machine.
Nov. 20	.263 x 1.79	.4708	.2657	10.0	57,136	30,799	1.16	11.6	43 6	28,309,000	Cut from flange of I beam.
Nov. 21	.280 x 1.81	.5068	.2679	10.0	60,970	32,556	2.49	24.9	47.1	29,232,000	Cut from flange of I beam.
Nov. 24	1.34 x .25	.3350	.1498	10.0	59,583	34,330	2.04	20.4	55.3	26,733,000	Cut from flange of I beam.
Nov. 24	.7700 dia.	.4657	.1662	11.0	62,556	46,171	2.75	25 0	64.3	29,073,000	Open hearth.
Nov. 25	.25 x 1.33	.3325	.2220	10.0	60,933	31,580	2.03	20.3	33.3	27,762,000	Cut from web of I beam.
Dec. 1	.7400 dia.	.4301	.2642	11.0	87,356	49,991	2.40	21.8	38.6	30,090,000	Bessemer.
Dec. 2	.7700 dia.	.4658	.1886	11.0	62,857	46,171	2 47	22.4	59 5	29,073,000	Open hearth.
Dec. 3	.28 x 1 80	.5040	.2537	10.0	60,754	34,722	2 53	25.3	49 7	29,395,000	Cut from flange of I beam.
Dec. 4	.7600 dia.	.4536	.2642	11.0	91,104	60,619	2.25	20.4	41.8	30,791,000	S. M. & Co. machine.
Dec. 5	.7600 dia.	.4536	.1627	11.0	64,315	45,189	2.70	24.5	64.1	29,843,000	Open hearth.

STEEL TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1891.											
March 2	.7575 dia.	.4507	.2552	11.0	90,750	58,800	2.13	19.3	43.4	30,995,000	S. M. & Co. machine.
March 3	.7650 dia.	.4596	.1626	11.0	63,527	44,600	2.56	23 3	64.6	29,008,000	Open hearth.
March 4	.7500 dia.	.4418	.2376	11.0	84,317	48,665	2.16	19.6	46.2	28,868,000	Bessemer.
March 5	.7420 dia.	.4330	.2290	11.0	80,720	49,650	2 25	20.5	47.2	29,887,000	Bessemer.
March 6	.7600 dia.	.4537	.1735	11 0	64,830	42,984	2.94	26.7	61.8	28,527,000	Open hearth.
March 6	.7550 dia.	.4477	.2507	11.0	92,362	56,960	2.10	19.1	44.0	29,782,000	S. M. & Co. extra machine.
March 9	.7550 dia.	.4477	.1886	11.0	65,020	45,790	2.81	25 5	57.9	29,338,000	Open hearth.
March 10	.25 x 1.85	.4625	.2482	10.0	64,000	33,513	1.69	16.9	46.3	30,345,000	Cut from flange of I beam, No. 340.
March 12	.7600 dia.	.4537	.1590	11.0	65,140	45,190	2 84	25.8	64.9	31,288,000	Open hearth.
March 13	.7575 dia.	.4507	.1698	11 0	65,240	43,270	2.88	26.2	62.3	30,040,000	Open hearth.
March 17	.7550 dia.	.4477	.2642	11.0	92,672	59,190	2.28	20.7	40.9	29,782,000	S. M. & Co. extra machine.
March 18	.24 x 1.39	.3336	.2340	10.0	61,750	31,474	1.75	17.5	29 9	29,482,000	Cut from web of I beam, No. 340.
March 19	.7575 dia.	.4507	.2463	11.0	91,530	58,800	2.13	19.4	45.3	31,498,000	S. M. & Co. extra machine.
March 23	.7550 dia.	.4477	.2642	11.0	92,250	59,190	2.38	21.6	40.9	30,710,000	S. M. & Co. extra machine.
March 24	.7575 dia.	.4507	.2463	15.0	91,590	58,800	2 84	19 0	45.4	29,586,000	S. M. & Co. extra machine.
March 24	.7575 dia.	.4507	.1810	15.0	65,125	45,487	3 53	23 5	59.9	29,912,000	Open hearth.
March 27	.7600 dia.	.4536	.1735	15.0	64,500	40,780	3.31	22.2	61.9	30,060,000	Open hearth.
March 30	.25 x 1.32	.3300	.2090	10 0	59,606	28,788	1.89	18.9	36.7	27,864,000	Cut from web of I beam, No. 341.
April 6	.7600 dia.	.4536	.2552	11 0	90,860	58,425	2.13	19 4	43.7	29,391,000	S. M. & Co. extra machine.
April 10	.7550 dia.	.4477	.1735	15.0	65,089	41,320	3.65	24.3	61 3	29,134,000	Open hearth.
Oct. 16	.7691 dia.	.4645	.1790	11 0	66,465	35,526	3.00	27.3	61.5	29,149,000	Bessemer.
Oct. 19	.7730 dia.	.4693	.1810	11.0	66,077	35,159	3 06	27.8	61.5	30,244,000	Bessemer.
Oct. 21	.7690 dia.	.4645	.1725	11.0	66,745	35,526	2.88	26.1	62.9	30,075,000	[50,000. S. M. & Co. tool steel. Did not break with actual load
Oct. 23	.7560 dia.	.4489	....	11.0	....	63,491	....	....	....	30,631,000	Bessemer.
Oct. 23	.7690 dia.	.4645	.1742	11.0	66,445	39,832	2.88	26.1	62.5	30,560,000	Bessemer.
Oct. 26	.7690 dia.	.4645	.1827	11.0	66,142	35,526	3.03	27.5	60.7	27,864,000	Bessemer.
Nov. 3	.7680 dia.	.4633	.1810	11.0	66,530	35,618	3 co	27.3	60.9	29,225,000	Bessemer.
Nov. 6	.7690 dia.	.4645	.1787	11.0	67,068	39,832	3 03	27.5	61.5	30,075,000	Not marked.
Nov. 14	.7596 dia.	.4532	.2019	11.0	51,151	18,756	2.18	19.9	44.4	28,983,000	Machine from F. D. & F.
Nov. 16	.7576 dia.	.4508	.2598	11.0	95,323	58,786	2.09	19.0	42.4	30,502,000	Bessemer.
Nov. 30	.7492 dia.	.4408	.2376	11.0	85,291	46,501	2.03	18.4	46.1	31,685,000	Machine.
Dec. 3	.7608 dia.	.4546	.2123	11.0	91,795	62,603	2 33	21.2	53.3	29,316,000	Machine.
Dec. 4	.7629 dia.	.4571	.2553	11.0	96,256	66,723	1.86	16.9	44.2	29,391,000	Machine.
Dec. 7	.7633 dia.	.4576	.2606	11.0	96,767	65,561	1.92	17.5	44.1	29,586,000	Bessemer.
Dec. 9	.7525 dia.	.4448	.3177	11.0	87,681	57,330	1.97	17.9	28.6	31,404,000	Bessemer.
Dec. 9	.7506 dia.	.4425	.3068	11.0	99,436	66,668	1.73	15 8	30.7	29,247,000	Machine.
Dec. 11	.7520 dia.	.4441	.2647	11.0	92,087	59,665	2.02	18 3	40.4	30,482,000	Machine.
Dec. 14	.7593 dia.	.4528	.2085	11.0	92,091	62,940	2.44	22.2	54.0	30,848,000	Bessemer.
Dec. 16	.7506 dia.	.4425	.3082	11.0	88,510	55,368	1 81	16.5	30 4	30,133,000	Bessemer.
Dec. 17	.7482 dia.	.4397	.2236	11.0	84,154	56,724	2 18	20.0	49 2	30,792,000	Machine.
Dec. 18	.7598 dia.	.4534	.2251	11.0	92,191	53,445	2.16	19.6	50.4	28,968,000	Machine.
Dec. 21	.7625 dia.	.4567	.2341	11.0	86,941	62,413	2.25	20.5	48.7	28,340,000	Bessemer
Dec. 23	.7517 dia.	.4438	.2372	11.0	93,219	59,713	2 05	18.6	46.5	31,475,000	

STEEL TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1892.											
March 3	.7623 dia.	.4564	.2546	11.0	95,750	62,445	2.0	18 2	46.2	30,604,000	Machine.
March 4	.7620 dia.	.4560	.2525	11.0	95,045	62,495	2.13	19.3	44.6	28,802,000	Machine.
March 7	.7511 dia.	.4430	.2290	11.0	94,810	59,820	2.0	18.2	48.3	30,100,000	Bessemer.
March 10	.7620 dia.	.4560	.2206	11.0	91,220	62,495	2.19	19.9	51.6	32,706,000	Machine.
March 16	.7504 dia.	.4423	.3413	11.0	101,300	64,442	1.70	15.5	22 8	30,148,000	Bessemer.
March 18	.7515 dia.	.4435	.2348	11 0	92,890	55,250	1.86	16.9	47.0	31,000,000	Bessemer.
March 22	.7560 dia.	.4489	.2570	11.0	96,684	63,490	2.18	19.9	42.8	29,400,000	Machine.
March 23	.7634 dia.	.4577	.2597	11.0	96,567	66,638	1.91	17.3	43.3	30,518,000	Machine.
March 23	.7506 dia.	.4425	.3019	11.0	98,284	64,410	1.75	15.9	31.8	30,134,000	Bessemer.
March 30	.7510 dia.	.4429	.2376	11.0	93,236	55,310	1.94	17.6	47.4	31,042,000	Bessemer.
March 30	.7500 dia.	.4418	.2193	11 0	83,750	55,457	2.25	20.5	50.4	29,293,000	Bessemer.
April 5	.7500 dia.	.4418	.2206	11.0	84,656	55,457	1.88	17.0	50.2	30,645,000	Bessemer.
Oct. 26	.7500 dia.	.4418	.2725	11.0	95,974	59,997	1.88	17.0	59.3	30,180,000	Bessemer.
Oct. 31	.7518 dia.	.4439	.2552	11.0	85,603	50,686	2 18	19.9	42 5	30,974,000	Bessemer.
Nov. 14	.7514 dia.	.4434	.2827	11.0	93,820	59,760	1.56	14.2	36.2	29,619,000	Bessemer.
Nov. 15	.7482 dia.	.4397	.2485	11.0	84,382	55,723	2.05	18.6	43.5	29,873,000	Bessemer.
Nov. 17	.7533 dia.	.4456	.3632	11.0	86,609	54,972	....	....	18.5	29,470,000	Bessemer. Broke in clamp.
Nov. 21	.7506 dia.	.4425	.2216	11.0	83,165	46,328	2.13	19.3	49.9	29,999,000	Bessemer.
Dec. 9	.7513 dia.	.4433	.3382	11 0	85,266	55,264	1.56	14 2	23.7	29,191,000	Bessemer.
Nov. 2	.7609 dia.	.4547	.2217	11.0	92,804	60,755	2.25	20 5	51.3	28,884,000	Machine.
Nov. 7	.7597 dia.	.4533	.2256	11.0	86,678	58,400	2 25	20.5	50.2	29,867,000	Machine.
Nov. 9	.7580 dia.	.4513	.2625	11.0	96,119	54,292	2.13	19.3	41.8	29,818,000	Machine.
Nov. 9	.7600 dia.	.4536	.2463	11.0	86,741	58,415	2.37	21.5	45.7	28,738,000	Machine.
Nov. 18	.7513 dia.	.4432	.3217	11.0	99,635	62,032	1.81	16.5	27.4	21,813,000	Machine.
Nov. 22	.7613 dia.	.4552	.2348	11.0	106,980	60,413	2.18	19.9	48.4	29,291,000	Machine.
Nov. 23	.7590 dia.	.4524	.2463	11.0	96,142	54,149	2.00	18 2	45.6	26,643,000	Machine.
Nov. 28	.7699 dia.	.4655	.2485	11.0	94,513	59,071	2.00	18 2	46 6	28,148,000	Machine.
Nov. 29	.7622 dia.	.4563	.2088	11.0	91,435	64,054	2.03	18.5	54.2	27,164,000	Machine.
Dec. 1	.7613 dia.	.4552	.2376	11.0	86,775	60,413	2.06	18.8	47.8	29,291,000	Machine.
Dec. 2	.7567 dia.	.4497	.2463	11.0	96,249	61,150	1.98	18.0	45.2	28,776,000	Machine.
Dec. 5	.7579 dia.	.4511	.2485	11.0	95,303	67,606	1.88	17.0	44 9	30,005,000	Machine.
Dec. 8	.40 x 1.50	.6000	....	10.0	60,000	30,832	....	....	....	31,746,000	Boiler.
Dec. 12	.359 x 1.5	.5391	....	10.0	52,439	34,311	1.13	11.3	....	30,306,000	Boiler.
Dec. 13	.390 x 1.5	.5859	....	10.0	58,368	29,866	1.00	10.0	....	26,256,000	Boiler.
Dec. 16	.40 x 1.5	.6000	....	10.0	59,716	27,500	....	....	....	28,986,000	Boiler.
1893.											
April 13	.7550 dia.	.4480	.1290	11.0	50,034	27,920	3.31	30.1	71.2	29,317,000	Bessemer
March 31	.7540 dia.	.4465	.2642	11.0	95,518	54,870	2.13	19.3	40.8	29,416,000	Machine.
March 29	.48 x 1.02	.4896	.2030	8.0	57,190	26,552	2.44	30.5	58 5	25,800,000	Plate.
March 31	.50 x 1.02	.5100	.2100	8.0	60,352	28,431	1.95	24.4	58.8	36,199,000	Plate.
April 3	.49 x 1.02	.4998	.2400	8.0	63,825	31,010	1.81	22.7	52.0	25,273,000	Plate.

STEEL TENSION.

Date.		Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1893.												
April	3	.49 x 1.02	.4998	.2059	8.0	60,024	29,012	1.88	23.4	58.8	26,677,000	Plate.
April	4	.50 x 1.02	.5078	.2479	8.0	59,803	29,012	2.16	26.9	50.5	30,012,000	Plate.
April	4	.49 x 1.02	.4998	.2059	8.0	61,024	29,012	2.09	26.2	58.8	30,012,000	Plate.
April	5	.50 x 1.02	.5100	.2039	8.0	60,393	29,412	1.94	24.2	60.2	29,412,000	Plate.
April	7	.49 x 1.02	.4998	.2695	8.0	63,625	30,012	1.86	23.2	46.1	31,866,000	Plate.
April	10	.49 x 1.02	.4998	.1870	8.0	50,480	26,041	2.34	29.3	62.5	33,051,000	Plate.
April	14	.39 x 1.28	.4826	.1940	8.0	53,543	29,009	2.31	28.9	59.8	26,168,000	Plate.
April	18	.38 x 1.27	.5207	.2604	8.0	58,144	27,846	1.94	24.2	50.1	35,455,000	Plate.
April	19	.41 x 1.27	.4539	.1116	11.0	46,866	27,598	3.88	35.2	69.0	25,564,000	Bessemer.
Nov.	17	.7594 dia.	.4530	.1160	11.0	79,460	27,591	3.38	30.7	74.4	30,350,000	Bessemer.
Nov.	18	.7595 dia.	.4547	.1360	11.0	52,780	27,490	3.44	33.5	70.1	27,257,000	Bessemer.
Nov.	20	.7609	.4411	.1644	11.0	51,240	28,340	3.06	27.8	62.8	29,777,000	Machine.
Nov.	21	.7494	.4481	.1093	11.0	*84,990	45,752	2.50	22.7	55.5	29,751,000	Boiler.
Nov.	22	.7554	.5121	.4125	10.0	49,404	34,172	....	....	19.5	27,407,000	Boiler.
Nov.	24	.3414 x 1.5	.5118	.4435	10.0	47,870	32,239	.88	8.8	13.3	27,913,000	Boiler.
Nov.	27	.3412 x 1.5	.4527	.1308	11.0	47,073	25,403	3.56	32.4	71.1	30,374,000	Bessemer.
Dec.	7	.7593 dia.	.4461	.1985	11.0	50,655	30,258	3.18	28.9	55.5	30,345,000	Bessemer.
Dec.	8	.7537 dia.	.4613	.0957	11.0	46,452	27,095	3.56	32.4	79.3	27,250,000	Bessemer.
Dec.	8	.7673 dia.	.4577	.1726	11.0	49,157	29,494	3.22	29.3	62.3	28,695,000	Bessemer.
Dec.	11	.7634 dia.	.4368	.1755	11.0	51,963	30,902	3.31	30.1	59.8	30,991,000	Bessemer.
Dec.	15	.7458 dia.	.4547	.1670	11.0	49,613	29,688	3.31	30.1	63.3	24,811,000	Bessemer.
Dec.	29	.7609 dia.	.4500	.1018	11.0	48,214	25,551	3.49	31.7	77.4	29,625,000	Bessemer.
1894.												
March	12	.8749 dia.	.6012	.2240	11.0	55,723	32,436	3.18	29.3	62.7	29,873,000	Rivet.
March	12	.8686 dia.	.5926	.2229	11.0	56,450	32,908	3.19	29.3	62.3	28,014,000	Rivet.
March	14	.8666 dia.	.5898	.2120	11.0	57,067	33,060	3.31	30.1	64.0	29,254,000	Rivet.
March	14	.8673 dia.	.5908	.2679	11.0	57,194	33,007	3.31	30.1	54.7	29,791,000	Rivet.
March	17	.8737 dia.	.5995	.2386	11.0	56,210	34,193	3.25	29.5	60.2	29,955,000	Rivet.
March	21	.7555 dia.	.4483	.1503	11.0	48,854	25,653	3.50	31.8	66.5	29,793,000	Bessemer.
March	26	.40 x 1.49	.5960	.4725	10.0	73,155	34,396	1.66	16.6	20.7	29,609,000	Girder plate.
March	28	.39 x 1.48	.5737	.4255	10.0	74,691	37,475	1.97	19.7	25.8	30,314,000	Girder plate.
March	28	.39 x 1.48	.5737	.4255	10.0	75,214	37,475	1.64	16.4	25.8	30,314,000	Girder plate.
April	2	.7526 dia.	.4448	.1267	11.0	48,555	28,099	3.50	32.3	71.5	23,226,000	Bessemer.
April	28	.475 x 1.0395	.4890	.1600	8.0	47,954	....	2.44	30.4	67.3	.....	Boiler.
April	28	.4702 x 1.0064	.4732	.1540	8.0	51,035	....	1.94	24.2	67.5	.....	Boiler.
April	28	.4292 x 1.0235	.4393	.1540	8.0	55,560	....	2.38	29.7	64.9	.....	Boiler.
April	28	.4258 x 1.0123	.4310	.1390	8.0	54,984	....	2.31	28.9	67.7	.....	Boiler.
April	28	.4225 x 1.0025	.4236	.1850	8.0	60,680	....	1.88	23.4	56.3	.....	Boiler.
April	28	.4125 x 1.0025	.4146	.1850	8.0	61,500	....	1.75	21.9	55.3	.....	Boiler.
May	11	.9960 x .3990	.3974	.3251	8.0	70,210	....	1.56	19.5	18.2	.....	Girder plate.
May	11	.9976 x .3989	.3980	.3282	8.0	71,000	....	0.81	10.2	17.6	.....	Girder plate.

WROUGHT IRON TENSION.

Date.	Section.	Original Section. (Lbs. per sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent)	Modulus of Elasticity.	Remarks.
1887.											
Nov. —	.7523 dia.	.4440	.1660	11.0	48,390	23,620	3.12	28.4	62.6	30,090,000	Norway.
Dec. 21	.7560 dia.	.4480	.1662	11.0	46,340	21,160	3.15	28.6	62.7	30,780,000	Norway.
Dec. 23	.7535 dia.	.4459	.1662	11.0	48,280	28,030	2.92	27.0	62 6	29,020,000	Norway.
Dec. 30	.7700 dia.	.4657	.1452	11.0	45,160	20,400	3.10	28.2	68 8	27,388,000	Norway.
Dec. 30	1.0108 dia.	.8024	.5541	11.0	54,420	29,280	2.67	24.3	30.1	28,400,000	American Tool & Machine Co.
Nov. 28	1.011 dia.	.8028	.5410	11.0	53,272	33,013	2.41	21.9	32.7	26,480,000	American Tool & Machine Co.
Nov. 29	.....	.8012	.5542	11.0	53,769	25,587	1.94	17.6	30.8	25,843,000	American Tool & Machine Co.
Dec. 12	1.011 dia.	.8028	.5030	11.0	56,787	30,510	2.45	22.3	37.0	26,732,000	American Tool & Machine Co.
1888.											
Feb. 7	.....	.8000	.5150	11.0	54,960	31,875	2.77	25.2	35.6	26,341,000	American Tool & Machine Co.
Feb. 8	1.013 dia.	.8063	.4902	11.0	48,867	26,666	2.10	19.1	39.2	28,823,000	American Tool & Machine Co.
Feb. 10	.7500 dia.	.4418	.1385	11.0	46,063	19,240	2.87	26.1	68.6	27,666,000	Norway.
Feb. 13	.7678 dia.	.4630	.1503	11.0	44,490	20,510	2.41	21.9	67.5	28,452,000	Norway.
Feb. 24	.7410 dia.	.4303	.1261	11.0	43,233	22,079	3.38	30.7	70.5	29,026,000	Norway.
March 2	.7470 dia.	.4383	.1075	11.0	43,470	19,400	3.39	30 8	75.5	26,700,000	Norway.
March 10	.7410 dia.	.4312	.1194	11.0	38,950	22,030	3.33	30.3	72.3	30,140,000	Norway.
March 13	.7420 dia.	.4324	.1070	11.0	43,240	21,970	2.90	26 4	75.2	27,726,000	Norway.
March 15	.7420 dia.	.4324	.1134	11 0	44,564	21,970	3.20	29.1	73.8	28,663,000	Norway.
March 22	.7420 dia.	.4324	.1075	11.0	43,860	19,658	2.26	20.5	75 0	18,000,000	Norway.
March 26	.6307 dia.	.3124	.1662	10.5	51,606	30,413	2.25	21.4	53.2	25,204,000	
March 29	.6300 dia.	.3117	.1886	11.0	53,890	33,680	2 55	23.0	39 5	27,340,000	
April 9	.....	.4359	.1930	11.0	44,390	....	2.26	20 5	56 0	27,731,000	
April 11	.5185 dia.	.2112	.1403	11.0	52,522	28,416	2.09	19.0	33.6	28,676,000	
Oct. 5	.7493 dia.	.4408	.2550	11.0	50,522	34,020	2.72	24.7	42.1	26,873,000	D. H. & Co.
Oct. 9	.7490 dia.	.4407	.2642	11.0	50,877	35,175	2.71	24 6	40.0	28,260,000	D. H. & Co.
Oct. 12	.7460 dia.	.4371	.3632	11.0	50,092	33,120	2.28	20 7	17.0	29,320,000	D. H. & Co.
Oct. 20	.7460 dia.	.4371	.3020	11.0	51,000	32,030	2.09	19 0	30.9	28,450,000	D. H. & Co.
Oct. 22	.7450 dia.	.4359	.3117	11.0	50,811	33,263	2.80	25.5	28 4	28,674,000	D. H. & Co.
Oct. 24	.7488 dia.	.4402	.2642	11.0	50,727	30,669	2.64	24.0	40.0	28,993,000	D. H. & Co.
Nov. 3	.7450 dia.	.4359	.2463	11.0	51,090	33,260	2.56	23.7	43.4	27,530,000	D. H. & Co.
Nov. 6	.7505 dia.	.4423	.2827	11.0	50,559	32,788	2.53	23.0	36 0	28,970,000	D. H. & Co.
Nov. 7	.7440 dia.	.4347	.2552	11 0	51,340	33,350	2.57	23.3	41.0	30,103,000	D. H. & Co.
Nov. 15	.7460 dia.	.4370	.3000	11.0	50,790	30,890	2 36	21.4	30.9	28,200,000	D. H. & Co.
Nov. 16	.7500 dia.	.4418	.2922	11.0	50,545	30,560	2.44	22.1	33.8	30,180,000	D. H. & Co.
Nov. 21	.7470 dia.	.4384	.2922	11.0	50,200	33,090	2.52	22.9	33.0	27,630,000	D. H. & Co.
Nov. 22	.7540 dia.	.4460	.2380	11.0	49,730	32,510	2.88	26.2	46.6	27,890,000	D. H. & Co.
Nov. 27	.7520 dia.	.4441	.3116	11.0	49,528	30,405	2.30	20.9	29.8	25,848,000	D. H. & Co.
Dec. 6	.7480 dia.	.4392	.2642	11.0	51,230	33,015	2.55	23.2	39.8	28,623,000	D. H. & Co.
Dec. 7	.7500 dia.	.4418	.2642	11.0	50,650	32,800	2.58	23.4	40.2	26,440,000	D. H. & Co.
Dec. 13	.7453 dia.	.4360	.3120	8 0	50,803	....	1.36	17.0	28.0	.....	D. H. & Co.
Dec. 21	.7550 dia.	.4477	.2552	11.0	52,710	32,380	2.56	23.3	43.0	26,549,000	Fall River Iron Works.
Dec. 21	.341 x 1.507	.5139	.3752	10.0	48,822	30,161	1.05	10.5	27.0	26,600,000	Boiler plate. Shell.
Dec. 28	.365 x 1.510	.5510	.3302	10.0	51,170	29,940	2.22	22.2	40.0	29,430,000	Boiler plate. Flange.

WROUGHT IRON TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1889.											
Feb. 18	.388 x 1.507	.5847	.5472	10.0	56,866	33,350	0.52	5.2	6.4	27,734,000	Flange fire-box iron.
Feb. 19	.413 x 1.505	.6216	.4958	10.0	60,170	49,070	1.19	11.9	20.2	27,980,000	Flange fire-box iron.
Feb. 26	.371 x 1.505	.5583	.4480	10.0	63,580	29,500	1.28	12.8	19.8	29,880,000	C. H. No. 1 iron.
March 5	.389 x 1.504	.5850	.5354	10 0	55,127	33,332	0.59	5.9	8.5	29,097,000	Flange fire-box iron.
March 5	.7540 dia.	.4465	.2734	11.0	51,176	30,235	2.50	22.7	38.8	29,563,000	D. H. & Co.
March 6	.385 x 1.508	.5806	.5424	10.0	58,562	31,865	0.49	4.9	6.6	27,286,000	Flange fire-box iron.
March 7	.385 x 1.507	.5802	.5220	10.0	57,194	31,886	0 53	5.3	10.0	28,430,000	Flange fire-box iron.
March 12	.7560 dia.	.4490	.2550	10.0	52,205	....	1.05	10.5	43.2	.....	D. H. & Co.
March 19	.411 x 1.504	.6180	.4700	10.0	61,000	33,200	1.15	11.5	24.0	28,130,000	Flange fire-box iron.
March 20	.412 x 1.504	.6196	.4323	10.0	58,750	33,088	0.95	9.5	30.2	29,684,000	Flange fire-box iron.
March 22	.414 x 1.504	.6227	.4995	10.0	59,640	31,300	1.07	10.7	19.8	28,749,000	Flange fire-box iron.
April 2	1.009 dia.	.7996	.2376	11 0	41,620	15,560	2.9	26.4	70.3	27,295,000	Norway.
April —	.370 x 1.515	.5606	.4480	10 0	61,700	22,300	1.06	10.6	20.0	29,800,000	C. H. No. 1 iron,
April 9	.371 x 1.514	.5617	.3915	10.0	61,860	36,400	1.19	11.9	30 3	27,650,000	C. H. No. 1 iron.
Oct. 10	.7560 dia.	.4478	.2375	11.0	52,025	34,610	2.94	26.7	47.0	24,779,000	D. H. & Co. merchant bar.
Oct. 10	.7535 dia.	.4458	.2734	11.0	52,400	30,282	2.65	24.1	38.7	28,746,000	D. H. & Co. merchant bar.
Oct. 14	.7502 dia.	.4420	.2376	11.0	51,807	35,067	1.79	16.3	46.2	34,300,000	D. H. & Co. merchant bar.
Oct. 17	.7500 dia.	.4418	.3101	11.0	51,720	35,083	2.50	22.7	44.2	27,664,000	D. H. & Co. merchant bar.
Oct. 24	.7555 dia.	.4477	.2551	11.0	53,607	34,629	2.18	19.8	42.9	27,917,000	D. H. & Co. merchant bar.
Oct. 28	.7560 dia.	.4489	.2827	11.0	50,790	34,530	2.63	23.9	37.0	33,221,000	D. H. & Co. merchant bar.
Oct. 29	.7570 dia.	.4501	.2376	11.0	51,502	32,217	2.33	21.0	47.0	28,960,000	D. H. & Co.
Oct. 31	.7570 dia.	.4501	.2552	11.0	51,590	34,429	2.42	22.0	43.0	28,474,000	D. H. & Co.
Dec. 31	1.0015 dia.	.7877	.4536	11.0	49,593	27,294	2.82	25.6	42.4	31,032,000	American Tool & Machine Co.
Oct. 15	.406 x 1 508	.6122	.3550	10.0	50,959	....	0.44	4.4	15.2	.....	Flange fire-box iron.
Nov. 12	.369 x 1.506	.5557	.3724	10.0	61,560	31,671	1.32	13.2	33.0	28,413,000	C. H. No. 1 iron.
Dec. 17	.365 x 1.505	.5490	.4020	10.0	61,130	....	1.16	11.6	26.9	.....	C. H. No. 1 iron.
Dec. 17	.373 x 1.505	.5613	.4544	10 0	56,410	34,736	0.37	3.7	19.1	27,404,000	C. H. No. 1 iron.
Nov. 13	.7553 dia.	.4479	.2827	11.0	50,208	....	2.53	23.0	37.0	.....	Fall River Iron Works.
Nov. 14	.7591 dia.	.4530	.2550	11.0	50,449	32,080	2.37	21.5	43.6	28,630,000	Fall River Iron Works.
Nov. 18	.7445 dia.	.4352	.3117	11.0	52,607	31,020	2.50	22.7	29.0	29,438,000	Fall River Iron Works.
Nov. 18	.7503 dia.	.4422	.2735	11.0	51,800	35,000	2.38	21.6	38.0	28,170,000	Fall River Iron Works.
Nov. 21	.7540 dia.	.4462	.2923	11.0	51,389	19,030	2.00	18.2	34.5	26,651,000	Fall River Iron Works.
Nov. 19	.7600 dia.	.4536	.3740	11 0	49,490	31,964	1.45	13.0	18.0	27,970,000	Fall River Iron Works.
Nov. 25	.7480 dia.	.4394	.2642	11.0	53,114	28,446	2.21	21.0	40.0	26,350,000	Fall River Iron Works.
Nov. 26	.7540 dia.	.4465	.2827	11.0	50,659	32,460	2.59	23.6	36.7	28,426,000	Fall River Iron Works.
Dec. 2	.7550 dia.	.4477	.3089	11.0	52,334	34,620	2.50	22.7	32.6	27,112,000	Fall River Iron Works.
Dec. 6	.7520 dia.	.4440	.2555	11.0	51,019	38,640	2.69	24.5	42.5	28,576,000	Fall River Iron Works.
Dec. 9	.7410 dia.	.4312	.2827	11.0	55,097	35,942	2.75	25 0	34.0	32,567,000	Fall River Iron Works.

WROUGHT IRON TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.	Elastic Limit. (Lbs. per sq. in.	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1890.											
Jan. 1	.9963 dia.	.7796	.4417	11.0	49,269	26,290	2.60	23.6	43.3	28,947,000	American Tool & Machine Co.
Feb. 24	.7500 dia.	.4418	.2376	11.0	52,759	32,820	2.81	25.6	46.2	29,880,000	McBarron & Co.
Feb. 25	.7500 dia.	.4418	.2376	11.0	52,285	32,820	2.75	25.0	46.2	29,292,000	McBarron & Co.
Feb. 26	.7560 dia.	.4488	.2552	11.0	50,835	32,308	2.45	22.3	43.1	28,281,000	McBarron & Co.
Feb. 27	.7600 dia.	.4536	.2123	11.0	48,941	29,762	2.44	22.2	53 2	28,527,000	McBarron & Co.
March 10	.7660 dia.	.4608	.3019	11.0	47,740	27,130	0.88	7.9	34.0	27,223,000	McBarron & Co.
March 13	.7625 dia.	.4567	.2463	11.0	50,900	31,750	2.63	23.9	46.1	30,097,000	McBarron & Co.
March 17	.7593 dia.	.4527	.3117	11.0	50,866	32,030	2.31	21.0	31.0	27,789,000	McBarron & Co.
March 19	.7662 dia.	.4611	.2485	11.0	49,630	29,278	2.52	22.8	46 0	25,291,000	McBarron & Co.
March 24	.7928 dia.	.4937	.2827	11.0	46,892	27,340	1.94	17.6	42.7	30,630,000	McBarron & Co.
March 27	.7662 dia.	.4610	.2549	11.0	50,496	29,282	2.16	19.6	44.7	26,029,000	McBarron & Co.
March 31	.7655 dia.	.4600	.2800	11.0	50,652	29,348	2.22	21.0	39.0	28,411,000	McBarron & Co.
April 7	.7560 d a.	.4489	.3048	11.0	51,617	30,075	2.34	21.3	32.1	28,006,000	McBarron & Co.
April 14	.7511 dia.	.4431	.2419	11.0	52,314	19,183	1.88	17.1	45.4	31,031,000	Broke in clamp.
April —	.7662 dia.	.4611	.2485	11.0	49,620	29,278	2.52	22.8	46 0	25,291,000	McBarron & Co.
Oct. 21	.7500 dia.	.4418	.1385	11.0	42,215	.....	3.09	28.2	68.6	29,292,000	Norway.
Oct. 24	.7500 d.a.	.4418	.1662	11.0	42,033	19,239	3.16	28.7	62 4	29,729,000	Norway.
Oct. 25	.7600 dia.	.4536	.1385	11.0	41,574	14,328	3.22	29.3	69 5	27,450,000	Norway.
Oct. 28	.7600 dia.	.4536	.1419	11.0	41,574	16,531	3.33	30.3	68.7	29,098,000	Norway.
Oct. 29	.7500 dia.	.4418	.1809	11.0	42,666	19,240	3.00	27.3	59 0	31,785,000	Norway.
Nov. 1	.7503 dia.	.4418	.2923	11.0	56,270	28,293	2.00	18.2	33.9	28,618,000	Refined.
Nov. 15	.7700 dia.	.4657	.3632	11.0	53,450	28,990	2.07	18.8	22.0	26,997,000	Refined.
Nov. 6	.7600 dia.	.4536	.3019	11.0	55,880	29,758	2.06	18.8	33.5	27,711,000	Refined.
Nov. 7	.7550 dia.	.4477	.2552	11.0	50,680	30,154	2.25	20.5	48 0	28,906,000	Youngstown.
Nov. 17	.7600 dia.	.4536	.1924	11.0	53,566	27,554	3.10	28.2	57.6	29,175,000	Burden's best.
Nov. 19	.7500 dia.	.4418	.2290	11.0	50,023	26,030	3.08	28.0	49.8	30,643,000	Burden's best.
Nov. 20	.7600 dia.	.4536	.2376	11.0	47,724	25,350	3.11	28.3	47.6	30,310,000	Burden's best.
Nov. 25	.7600 dia.	.4536	.2042	11.0	52,067	29,759	2.75	25.0	41.8	28,113,000	Youngstown.
1891.											
March 2	.7700 dia.	.4657	.2552	11.0	46,772	24,700	2.86	26.1	45.2	28,347,000	Burden's best.
March 3	.34 x 1.24	.4216	.3720	10.0	45,707	22,533	.475	4.75	11.8	26,355,000	Cut from web of I beam, No. 341.
March 4	.7700 dia.	.4657	.2507	11.0	46,600	22,550	2.83	25.7	46.2	29,528,000	Burden's best.
March 5	.33 x 1.25	.4125	.3600	10.0	48,360	25,450	0.75	7.5	12.7	25,080,000	Cut from web of I beam, No. 341.
March 12	.7700 dia.	.4657	.2507	11.0	47,395	22,550	3 09	28.1	46.2	28,347,000	Burden's best.
March 12	.7500 dia.	.4418	.1320	11.0	41,875	16,978	3.53	32.1	70.1	30,487,000	Norway.
March 16	.7525 dia.	.4447	.1810	11.0	43,396	19,112	3.15	28.6	59.3	28,000,000	Norway.
March 16	.7650 dia.	.4596	.2923	11.0	54,565	27,195	2.50	22.7	36.4	28,160,000	Norway.
March 18	.7650 dia.	.4596	.3068	11.0	53,850	29,370	2.31	21.0	33.3	28,718,000	Refined.
March 23	.7675 dia.	.4627	.2376	15.0	47,963	22,695	4.00	26.7	48.6	29,475,000	Burden's best.
March 25	.33 x 1.47	.4851	.2944	14.0	47,640	23,706	2.14	15.3	39.3	27,485,000	Cut from flange of I beam, No. 341.
March 27	.37 x 1.47	.5402	.3584	10 0	51,462	24,990	1.81	18.1	33.8	29,230,000	Cut from flange of I beam, No. 341.
March 31	.33 x 1.23	.4059	.3105	10.0	45,927	23,405	1.02	10.2	23.5	29,503,000	Cut from web of I beam, No. 340.
April 7	.35 x 1.46	.5110	.3500	14.0	50,156	22,505	2.34	16.7	31.5	29,354,000	Cut from flange of I beam, No. 341.
April 8	.31 x 1.46	.4526	.3048	10.0	50,330	25,410	1.84	18.4	32.7	.....	Cut from flange of I beam, No. 341.

WROUGHT IRON TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1891.											
Oct. 12	.7650 dia.	.4596	.3016	11.0	52,770	33,722	1.63	14.8	14.8	27,355,000	Refined.
Oct. 12	.7685 dia.	.4639	.2845	11.0	47,860	26,948	2.66	24.2	46.4	26,948,000	Burden's best.
Oct. 16	.7431 dia.	.4336	.2881	11.0	52,770	28,829	2.56	23.3	33.5	29,273,000	Refined.
Oct. 19	.7480 dia.	.4394	.3473	11.0	51,138	37,548	1.16	10.5	21.0	27,814,000	
Oct. 23	.7540 dia.	.4465	.3421	11.0	53,167	32,474	2.91	26.4	23.4	30,166,000	
Oct. 26	.7530 dia.	.4453	.3084	11.0	53,332	34,806	2.38	21.6	30.8	27,445,000	
Nov. 2	.7515 dia.	.4459	.2827	11.0	52,700	30,274	2.13	19.3	36.6	26,430,000	
Nov. 2	.7560 dia.	.4490	.3157	11.0	52,241	34,530	2.44	22.2	29.7	26,733,000	
Nov. 6	.7520 dia.	.4442	.3078	11.0	53,518	32,647	2.41	21.9	30.7	29,137,000	
Nov. 9	.7588 dia.	.4522	.2603	11.0	52,298	27,642	2.72	24.7	42.5	27,028,000	Youngstown.
Nov. 10	.7688 dia.	.4642	.2680	11.0	47,500	26,927	3.34	30.4	42.3	28,435,000	Burden's best.
Nov. 11	.7550 dia.	.4477	.2715	11.0	53,161	30,154	2.84	25.9	39.3	28,350,000	Youngstown.
Nov. 11	.7660 dia.	.4608	.3568	11.0	51,320	29,294	1.11	11.1	22.6	28,082,000	Refined.
Nov. 13	.7658 dia.	.4606	.3438	11.0	53,778	27,138	2.09	19.0	25.4	28,659,000	Refined.
Nov. 16	.7375 dia.	.4272	.1144	11.0	39,210	15,216	3.81	34.7	73.2	30,294,000	Norway.
Nov. 30	.7453 dia.	.4364	.1295	11.0	40,343	12,603	3.38	30.7	70.5	28,810,000	Norway.
Dec. 2	.7618 dia.	.4558	.2135	11.0	47,610	23,036	3.25	29.5	53.1	29,551,000	Burden's best.
Dec. 2	.7382 dia.	.4280	.1296	11.0	39,896	15,187	3.45	31.4	69.7	31,153,000	Norway.
Dec. 4	.7435 dia.	.4342	.1022	11.0	39,156	16,123	4.17	38.0	76.4	29,807,000	Norway.
Dec. 7	.7670 dia.	.4620	.2348	11.0	49,238	22,725	2.59	23.6	49.2	27,470,000	Burden's best.
Dec. 8	.7579 dia.	.4512	.2092	11.0	50,037	27,700	2.89	26.3	53.6	29,251,000	Burden's best.
Dec. 11	.7646 dia.	.4592	.2352	11.0	48,538	27 224	2.88	26.1	48.8	29,355,000	Burden's best.
Dec. 14	.7591 dia.	.4525	.2127	11.0	50,660	23,201	2.94	26.7	53.0	31,028,000	Burden's best.
Dec. 14	.7584 dia.	.4517	.2240	11.0	49,143	23,240	3.31	30.1	50.4	30,438,000	Burden's best.
Dec. 16	.7578 dia.	.4510	.2878	11.0	51,716	25,537	2.44	22.2	36 3	28,141,000	Youngstown.
Dec. 18	.7556 dia.	.4484	.2693	11.0	52,408	32,336	2.50	22.7	39 9	28,305,000	Youngstown.
Dec. 21	.7553 dia.	.4481	.2256	11.0	48,655	23,414	3.14	28.6	49.6	30,062,000	Burden's best.
Dec. 23	.7645 dia.	.4590	.2140	11.0	47,220	22,880	3.20	29.1	53.4	29,969,000	Burden's best.
1892.											
March 2	.7620 dia.	.4560	.2090	11 0	47,090	23,020	3.19	29.0	54.1	33,657,000	Burden's best.
March 3	.7390 dia.	.4289	.1296	11.0	41,030	17,400	3.59	32.7	69.8	29,310,000	Norway.
March 5	.7610 dia.	.4548	.2124	11.0	49,690	27,480	2.98	27.1	53.3	29,614,000	Burden's best.
March 8	.7282 dia.	.4165	.1146	11.0	41,180	18,000	3.59	32.7	72.5	31,073,000	Norway.
March 9	.7633 dia.	.4575	.2206	11.0	47,430	22,950	3.02	27.4	51.8	29,443,000	Burden's best.
March 28	.7625 dia.	.4565	.1964	11.0	47.950	23,000	3.93	29.4	57 0	29,504,000	Burden's best.
April 1	.7549 dia.	4475	.3247	11.0	53,190	27,936	2.28	20 7	27.4	26,818,000	
April 4	.7530 dia.	.4453	.2942	11.0	52,770	23,578	2.63	23.9	33.9	27,446,000	
April 6	.7420 dia.	.4324	.1385	11.0	42,320	19,660	3 09	28.1	68.0	30,834,000	Norway
April 11	.7530 dia.	.4453	.2986	11.0	50,750	32,560	2.53	23.0	32.9	26,947,000	
April 13	.7540 dia.	.4465	.2913	11.0	53,240	23,520	...	...	34 8	26,398,000	

WROUGHT IRON TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension. (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1892.											
Oct. 27	.7590 dia.	.4525	.2730	11.0	49,232	32,047	2.68	24.4	39.7	29,170,000	
Nov. 4	.7642 dia.	.4587	.2485	11.0	49,381	22,892	2.75	25.0	45.8	28,779,000	Burden's best.
Nov. 7	.7387 dia.	.4286	.1296	11.0	43,913	19,833	3.06	27.8	69.8	26,970,000	Norway.
Nov. 9	.7665 dia.	.4614	.2463	11.0	49,411	18,420	2.63	23.9	46.6	30,112,000	Burden's best.
Nov. 11	.7595 dia.	.4531	.2206	11.0	49,660	23,186	3.18	29.0	51.3	30,160,000	Burden's best.
Nov. 15	.7378 dia.	.4275	.0928	11.0	42,102	19,881	...	..	78.3	29,127,000	Norway.
Nov. 16	.7358 dia.	.4252	.1257	11.0	39,698	17,638	3.5	31.8	70.5	30,023,000	Norway.
Nov. 21	.7600 dia.	.4536	.1964	11.0	48,055	20,940	3.00	27 3	56.7	28,809,000	Burden's best.
Nov. 22	.7695 dia.	.4651	.2769	11.0	49,026	22,578	2.88	26.1	40.5	27,292,000	Burden's best.
Nov. 23	.7315 dia.	.4203	.1320	11.0	43,187	17,846	4.44	40.3	68.6	28,553,000	Norway.
Nov. 29	.7320 dia.	.4208	.1104	11.0	40,669	17,820	1.50	13.6	73.8	30,159,000	Norway.
Nov. 30	.7329 dia.	.4219	.1296	11.0	39,348	16,593	3.56	32.4	69.3	29,518,000	Norway.
Nov. 30	.7343 dia.	.4235	.0909	11.0	39,671	12,987	3.63	32.9	78.1	28,861,000	Norway.
Dec. 2	.7520 dia.	.4442	.1014	11.0	39,951	16,886	3.63	32.9	77.2	30,020,000	Norway.
Dec. 6	.7372 dia.	.4268	.1104	11.0	41,093	16,400	3.28	29.8	74.1	28,634,000	Norway.
Dec. 7	.7373 dia.	.4270	.1014	11.0	40,192	14,053	3.69	33.5	76.3	28,627,000	Norway.
Dec. 7	.7274 dia.	.4156	.1104	11.0	44,470	16,844	2.94	26.8	73.4	31,114,000	Norway.
Dec. 12	.7382 dia.	.4280	.0935	11.0	41,940	17,523	...	..	78.5	29,373.000	Norway.
Dec. 13	.7361 dia.	.4256	.1256	11.0	42,532	16,449	3.31	30.1	70.5	30,410,000	Burden's best.
Dec. 14	.7614 dia.	.4553	.2043	11.0	47,220	23,060	3.00	27.3	51.2	33,710,000	
1893.											
March 29	.7600 dia.	.4536	.2290	11.0	50,149	20,940	2.88	26.1	41.5	27,450,000	Burden's best.
March 31	.7431 dia.	.4337	.3739	11.0	48,882	28,822	0.94	8.5	13.8	28,713,000	Refined.
April 5	.7500 dia.	.4418	.1134	11.0	48,553	23,767	3.63	32.9	74 3	31,124,000	Burden's best.
April 5	.7500 dia.	.4418	.1613	11.0	49,350	21,503	3.50	31.8	66.5	31,793,000	Burden's best.
April 7	.7600 dia.	.4536	.2206	11.0	50,083	20,940	2.88	26.1	51 4	29,097,000	Burden's best.
April 10	.7600 dia.	.4536	.2206	11.0	47,019	23,146	3.03	27.5	51 4	29,978,000	Burden's best.
April 11	.7600 dia.	.4536	.2124	11.0	47,504	20,942	3.13	28.4	53.2	28,527,000	Burden's best.
April 12	.7600 dia.	.4536	.2290	11.0	47,747	20,942	4.06	36.9	49.5	29,874,000	Burden's best.
April 13	.7550 dia.	.4477	.2376	11.0	50,927	23,453	3.06	27.8	46.9	28,350,000	Burden's best.
April 14	.7500 dia.	.4418	.2124	11.0	51,269	21,182	3.31	30.1	51.9	32,551,000	Burden's best.
April 14	.7500 dia.	.4418	.2043	11.0	50,930	23,770	3.18	29.0	53.7	29,293,000	Burden's best.
April 17	.7600 dia.	.4536	.2485	11.0	50,083	23,146	3.18	29.0	45.2	29,097,000	Burden's best.
April 20	.7500 dia.	.4418	.1963	11.0	48,168	23,767	3.06	27.8	55.6	29,879,000	Burden's best.
Oct. 26	.7513 dia.	.4433	.3811	11.0	49,240	28,190	1.13	10.2	14.0	27,520,000	Refined.
Oct. 27	.7496 dia.	.4413	.3624	11.0	50,190	30,590	...	..	17.8	26,237,000	Refined.
Oct. 30	.7665 dia.	.4614	.3624	11.0	51,460	29,256	2.06	18.8	22.4	25,680,000	Refined.
Oct. 31	.7521 dia.	.4442	.3890	11.0	47,495	30,387	0.75	6.8	12.2	27,613,000	Refined.
Nov. 4	.7498 dia.	.4416	.3652	11.0	48,352	30,574	0.75	6.8	17.3	27,177,000	Refined.
Nov 6	.7559 dia.	.4488	.1104	11.0	47,151	25,982	3 91	35 5	75.4	21,628,000	Refined.
Nov. 8	.7669 dia.	.4619	.3449	11.0	50,351	35,720	2.34	21.3	25 3	27,477,000	Refined.
Nov. 10	.7470 dia.	.4383	.3739	11.0	48,202	28,521	1.00	9.0	14.7	27,888,000	Refined.
Nov. 11	.7500 dia.	.4418	.3846	11.0	50,703	30,558	1.50	13.6	13.0	23,713,000	Refined.
Nov. 14	.7505 dia.	.4423	.3750	11.0	49,223	30,517	1.13	10.2	15.2	27,126,000	Refined.

CAST IRON TENSION.

Date.	Dimensions.	Original Section. (Sq. in.)	Maximum Load. (Lbs. per sq. in.)	Modulus of Elasticity.	Remarks.
1888.					
March 6	.629 x 1.006	.6328	15,566	9,365,000	Cut from interior of beam No. 2.
April 16	1.02 x 1.04	1.0608	20,758	14,787,000	South Boston Iron Works.
Oct. 26	1.141 x 1.159	1.3214	20,185	.....	Foundry, rough.
Oct. 30	1.138 x 1.181	1.344	20,238	.....	Foundry, rough.
Nov. 19	1.0029 x 1.0029	1.0058	23,454	11,630,000	Planed.
Dec. 14	1.0067 x 1.0049	1.0117	21,300	10,980,000	Planed.
1889.					
Feb. 26	1.0038 x 1.0035	1.0073	21,810	9,928,000	Planed.
Feb. 27	1.0006 x 1.0015	1.0021	22,353	11,975,000	Planed.
March 25	1.0042 x 1.0042	1.0084	21,950	12,400,000	Planed.
April 8	1.175 x 1.175	1.2806	18,550	13,580,000	Rough.
1890.					
Feb. 25	1.14 x 1.16	1.3224	15,124	10,312,000	American Tool & Machine Co.
Feb. 27	1.15 x 1.14	1.3110	16,499	11,300,000	American Tool & Machine Co.
March 4	1.15 x 1.15	1.3225	19,200	11,483,000	American Tool & Machine Co.
March 6	.....	1.6200	14,304	8,613,000	American Tool & Machine Co.
March 10	1.2 x 1.19	1.428	17,770	10,260,000	American Tool & Machine Co.
March 13	1.12 x 1.15	1.288	17,663	10,709,000	American Tool & Machine Co.
March 17	1.20 x 1.18	1.416	15,537	11,278,000	American Tool & Machine Co.
March 19	1.13 x 1.14	1.248	20,390	9,811,000	American Tool & Machine Co.
March 24	1.16 x 1.20	1.390	18,849	10,277,000	American Tool & Machine Co.
March 27	1.14 x 1.14	1.300	17,643	12,311,000	American Tool & Machine Co.
March 31	1.15 x 1.17	1 346	13,734	11,428,000	American Tool & Machine Co.
April 7	1.22 x 1.23	1.500	6,667	10,254,000	American Tool & Machine Co.
April 9	1.16 x 1.16	1.346	19,248	10,550,000	American Tool & Machine Co.
April 11	1.13 x 1.14	1 288	18,631	13,801,000	American Tool & Machine Co.
April 15	1.13 x 1.13	1.265	17,391	12,151,000	American Tool & Machine Co.
Oct. 14	1.015 x 1.015	1.030	18,295	12,926,000	
Oct. 17	1.00 x 1.00	1.000	15,900	12,000,000	
Oct. 20	1.00 x 1.03	1.031	20,398	12,665,000	
Oct. 21	1.03 x 1.03	1.063	16,275	11,520,000	
Oct. 23	1.02 x 1.01	1.030	18,977	11,648,000	
Oct. 27	1.00 x 1.00	1.000	17,180	11,111,000	
Oct. 29	1.01 x 1.01	1.020	17,715	13,667,000	
Oct. 30	1.01 x 1.01	1.020	21,782	12,639,600	
Nov. 3	1.04 x 1.03	1.071	22,017	13,664,000	
Nov. 6	1.02 x 1.02	1.040	23,077	14,787,000	
Nov. 7	1.01 x 1.02	1.030	19,592	12,664,000	
Nov. 13	1.02 x 1.01	1.030	19,219	11,881,000	
Nov. 14	1.03 x 1.03	1.061	22,095	13,791,000	
Nov. 17	1.01 x 1.01	1.020	18,057	13,370,000	
1890.					
Nov. 18	1.01 x 1.04	1.050	21,323	13,289,000	
Dec. 1	1.00 x 1.01	1.010	18,812	12,914,000	
Dec. 4	1.03 x 1.03	1.061	20,238	12,852,000	
Dec. 5	1.01 x 1.01	1.020	17,647	14,005,000	
1891.					
March 2	1.02 x 1.03	1.051	18,658	13,593,000	
March 3	1.01 x 1.01	1.020	17,537	13,070,000	
March 4	1.00 x 1.01	1.010	18,405	12,640,000	
March 5	1.00 x 1.02	1.020	19,560	11,999,000	
March 18	1.01 x 1 03	1.040	19,000	13,112,000	
March 23	1.02 x 1.03	1.051	19,200	14,278,000	
March 25	1.00 x 1.00	1.00	17,700	12,000,000	
March 27	.98 x .98	.9604	20,356	12,320,000	
March 31	1.00 x 1.00	1.00	18,160	13,043,000	
April 7	1.01 x 1.01	1.020	20,302	12,199,000	
April 8	.99 x 1.01	.9999	19,172	11,766,000	
Oct. 17	1.022 x 1.056	1.079	17,512	12,409,000	
Oct. 21	1.045 x 1.020	1.066	18,100	12,509,000	
Oct. 23	1.03 x 1.02	1.0475	23,967	14,323,000	
Oct. 23	1.014 x 1.002	1 016	21,112	14,764,000	
Oct. 23	1.00 x 1.02	1.016	17,723	14,769,000	
Oct. 28	1.00 x 1.00	1.00	21,810	15,789,000	
Nov. 3	1.03 x 1.06	1.096	22,845	14,801,000	
Nov. 6	1.03 x 1.02	1.047	22,153	13,656,000	
Nov. 9	1.00 x 1.02	1.016	18,678	14,769,000	
Nov. 11	1.00 x 1 02	1.016	19,693	14,769,000	
Nov. 14	1.06 x 1.06	1.031	18,799	14,915,000	
Nov. 16	1.00 x 1.02	1.016	18,609	15,148,000	
Dec 1	.....	1.023	21,740	14,298,000	
Dec. 3	1.03 x 1.09	1.128	20,667	13,300,000	
Dec. 4	1.01 x 1.01	1.012	18,558	14,807,000	
Dec. 8	1.03 x 1.03	1.064	21,084	14,848,000	
Dec. 9	1.047 x 1.031	1.079	22,159	14,624,000	
Dec. 10	1.02 x 1.04	1.063	16,367	14,110,000	
Dec. 11	1.03 x 1.06	1.096	17,798	13,446,000	
Dec. 15	1.05 x 1.02	1.064	21,635	13,766,000	
Dec. 17	1.007 x 1.006	1.035	19,289	15,558,000	
Dec. 18	1.023 x 1.021	1.147	20,666	14,949,000	
Dec. 19	1.031 x 1.00	1.031	21,091	14,545,000	
Dec. 21	1.00 x 1.031	1.031	21,150	14,920,000	
Dec. 23	1 00 x 1.01	1.012	22,187	14,818,000	

CAST IRON TENSION.

Date.	Dimensions.	Original Section. (Sq. in.)	Maximum Load. (Lbs. per sq. in.)	Modulus of Elasticity.	Remarks.
1892.					
March 1	1.02 X 1.04	1.063	19,340	14,857,000	
March 2	1.03 X 1.02	1.047	23,910	15,481,000	
March 7	1.00 X .98	.9844	21,180	15,238,000	
March 16	1.00 X .97	.9687	23,227	15,881,000	
March 22	1.02 X 1.06	1.079	19,830	14,539,000	
March 31	1.00 X 1.03	1.031	20,413	17,632,000	
Oct. 27	.93 X 1.00	.9300	16,774	14,337,000	
Oct. 28	1.00 X 1.00	1.00	18,600	15,383,000	
Oct. 31	1.00 X 1.00	1.00	18,000	16,666,000	
Nov. 5	1.00 X 1.00	1.00	19,400	17,911,000	
Nov. 7	1.00 X 1.00	1.00	20,950	15,789,000	
Nov. 9	1.00 X 1.00	1.00	22,900	15,000,000	
Nov. 14	1.00 X 1.00	1.00	22,400	15,564,000	
Nov. 14	1.00 X 1.00	1.00	21,300	15,384,000	
Nov. 15	1.00 X 1.02	1.02	19,692	15,966,000	
Nov. 17	1.02 X 1.03	1.047	21,005	15,075,000	
Nov. 18	1.076 X 1.233	1.327	20,600	11,900,000	
Nov. 21	1.00 X 1.031	1.031	17,067	12,676,000	
Nov. 28	1.00 X 1.031	1.031	19,900	12,929,000	
Nov. 28	.98 X 1.03	1.015	16,404	12,577,000	
Nov. 28	1.00 X 1.02	1.015	16,450	12,570,000	
Nov. 29	1.00 X 1.00	1.00	17,100	13,333,000	
Dec. 1	1.00 X 1.02	1.02	19,068	13,680,000	
Dec. 2	1.00 X 1.00	1.00	18,000	13,333,000	
Dec. 5	1.00 X 1.016	1.016	19,299	12,057,000	
Dec. 8	1.06 X .98	1.029	17,488	13,249,000	
Dec. 9	1.00 X .984	.9840	19,500	13,250,000	
Dec. 12	1.02 X 1.02	1.031	20,747	14,543,000	
Dec. 13	1.03 X 1.03	1.063	18,620	13,434,000	
Dec. 16	1.00 X 1.00	1.00	18,910	13,043,000	
1893.					
March 29	1.00 X 1.00	1.00	19,900	15,000,000	
April 3	1.00 X 1.016	1.016	19,594	13,373,000	
April 3	1.01 X 1.03	1.04	16,341	13,108,000	
April 4	1.01 X 1.03	1.04	13,844	13,640,000	
April 5	1.02 X 1.08	1.012	13,798	11,840,000	
April 7	1.00 X 1.02	1.02	17,647	12,787,000	
April 10	1.03 X 1.03	1.061	14,025	12,568,000	
April 11	1.04 X 1.02	1.060	15,083	13,466,000	
April 14	1.02 X 1.04	1.060	16,874	9,751,900	
April 18	1.00 X 1.00	1.00	20,000	13,043,000	

COMPRESSIVE TESTS, WROUGHT IRON.

Date.	Section.	Original Section. (Sq. in.)	Total length. (Inches.)	Gauged length. (Inches.)	Modulus of Elasticity.	Remarks.
1887.						
Nov. 1	1.003 dia.	.7901	6.0	5.0	29,300,000	American Tool & Machine Co.
Nov. 11	....	.7971	6 0	5.0	27,274,000	American Tool & Machine Co.
Nov. 14	1.007	.7964	6.0	5.0	27,414,000	American Tool & Machine Co.
Nov. 17	1.006	.7948	6.0	5.0	27,570,000	American Tool & Machine Co.
Nov. 31	....	.7983	6.0	5.0	27,090,000	American Tool & Machine Co.
Dec. 1	....	.7950	6.0	5.0	29,028,000	American Tool & Machine Co.
Dec. 12	1.007	.7970	6.0	5.0	27,248,000	American Tool & Machine Co.
Dec. 14	1.005	.7939	6.0	5.0	28,306,000	American Tool & Machine Co.
Dec. 28	1.008	.7980	6.0	5.0	29,480,000	American Tool & Machine Co.
Dec. 29	1.006	.7949	6.0	5.0	25,585,000	American Tool & Machine Co.
1888.						
Feb. 14	.8788 x .8780	.7716	4.0	1.995	25,727,000	Cut from comp. side of beam No. 1.
Feb. 15	.514 x 1.009	.5186	...	3.98	25,707,000	Cut from tension side of beam No. 1.
Feb. 24	1.007 dia.	.7964	6.0	5.0	26,806,000	
March —	.878 x .878	.7718	3.0	1.995	25,665,000	Cut from beam No. 1.
March 20	1.008 dia.	.7980	6.0	5.0	27,241,000	American Tool & Machine Co.
Nov. 12	.997 dia.	.7807	6.0	5.0	27,253,000	American Tool & Machine Co.
Dec. 10	.998 dia.	.7822	6.0	5.0	27,700,000	American Tool & Machine Co.
Dec. 17	.998 dia.	.7823	6.0	5.0	24,350,000	American Tool & Machine Co.
Dec. 26	.9975 dia.	.7816	6.0	5.0	26,120,000	American Tool & Machine Co.
1889.						
Feb. 28	.9965 dia.	.7799	6.0	5.0	27,281,000	American Tool & Machine Co.
March 27	.9962 dia.	.7794	6.0	5.0	26,720,000	American Tool & Machine Co.

COMPRESSIVE TESTS, CAST IRON.

Date.	Section.	Original Section. (Sq. in.)	Total Length. (Inches.)	Gauged Length. (Inches.)	Modulus of Elasticity.	Remarks.
1887.						
Oct. 8	.8759 x .8769	.7681	3.71	4 5	13,801,000	So. Boston Iron Works.
Oct. 15	.8766 x .8766	.7664	3.60	4.5	11,663,000	So. Boston Iron Works.
Oct. 21	.880 x .881	.7753	3.59	4.5	11,576,000	So. Boston Iron Works. Cut from beam No. 1.
Oct. 25	.875 x .875	.7656	3.62	4 5	10,363,000	So. Boston Iron Works. Cut from beam No. 1.
Oct. 28	....	.7712	3.62	4.5	19,957,000	So. Boston Iron Works. Cut from beam No. 1.
1888.						
Feb. 17	1.004 x 1.003	1.007	4.00	5.0	10,709,000	American Tool & Machine Co.
March 7	1.006 x 1.003	1.009	3.99	5.0	9,049,000	American Tool & Machine Co.
March 13	1.006 x 1.003	1.009	4 00	5 0	8,157,000	American Tool & Machine Co.
March 1	1.006 x 1.003	1.009	4.00	5.0	8,156,000	American Tool & Machine Co.
March 29	1.00 x 1.00	1.00	3.99	5 0	8,400,000	Cut from interior of beam No. 3, T section.
April 2	1.00 x 1.00	1.00	4.00	5.0	8,649,000	Cut from comp. side beam No. 3.
April 10	1 091 x 1.001	1.002	4.00	5.0	7,523,000	Cut from interior of beam No. 3.
Oct. 11	1.003 x 1.003	1.006	4.02	5.0	11,528,000	Planed. American Tool & Machine Co.
Oct. 16	1.059 x 1.059	1.121	4.00	5.0	9,843,000	American Tool & Machine Co.
Oct. 17	1.008 x 1.006	1.014	4.01	5.0	11,123,000	American Tool & Machine Co.
Oct. 21	1.004 x 1.004	1.008	4.00	5.0	10,761,000	American Tool & Machine Co.
Nov. 28	1.004 x 1.004	1.008	4.0	5 0	10,987,000	American Tool & Machine Co.
Dec. 5	1.004 x 1.004	1.008	4.0	5.0	11,900,000	American Tool & Machine Co.
Dec. 5	1.004 x 1.004	1.008	4.0	5.0	12,200,000	American Tool & Machine Co.
Dec. 31	1.002 x 1.002	1.004	4 0	5.0	12,528,000	American Tool & Machine Co.
1889.						
Jan. 1	1.004 x 1.005	1.009	4.0	5.0	11,330,000	American Tool & Machine Co.
March 1	1.002 x 1.001	1.003	4.0	5.0	11,394,000	American Tool & Machine Co.
March 12	1.003 x 1.003	1.006	4.0	5.0	12,915,000	American Tool & Machine Co.
March 12	1.003 x 1.003	1.006	4.0	5.0	12,723,000	American Tool & Machine Co.
March 15	1.004 x 1.004	1.008	4.0	5.0	13,200,000	American Tool & Machine Co.

MISCELLANEOUS TESTS — TENSION.

Date.	Section.	Original Section. (Sq. in.)	Fractured Section. (Sq. in.)	Gauged Length. (Inches.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Ultimate Extension (Inches.)	Ultimate Extension. (Per cent.)	Reduction of Area. (Per cent.)	Modulus of Elasticity.	Remarks.
1887.											
Oct. 14	.047 dia.	.001734	....	10.0	80,740	....	....	....	....	....	Phosphor bronze wire.
Nov. 11	.047 dia.	.001734	....	10.0	98,000	....	....	....	....	....	Phosphor bronze wire.
1894.											
April 4	.8020 dia.	.5052	.3083	11.0	16,034	10,888	0.31	2.8	39.0	10,012,000	Aluminum.
April 6	.8024 dia.	.5057	.2748	11.0	14,434	8,899	2.44	22.2	45.7	13,184,000	Aluminum.

IRON WIRE TESTS.

Date.	Diameter.	Original Section. (Sq. in.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Modulus of Elasticity.	Remarks.
1887.	.135					
Oct. 14	.135	.01431	70,006	....	....	Galvanized.
Oct. 14		.01431	74,752	....	....	Galvanized.
Oct. 14	.192	.02895	69,080	....	....	Galvanized.
Oct. 14	.192	.02895	68,385	....	....	Galvanized.
Nov. 11	.192	.02895	72,879	....	....	Galvanized.
Nov. 11	.192	.02895	72,180	....	....	Galvanized.
Nov. 11	.135	.01431	67,772	....	....	Galvanized.
Nov. 11	.135	.01431	71,263	....	....	Galvanized.
Nov. 11	.105	.008659	63,517	....	....	Galvanized.
Nov. 11	.105	.008659	70,448	....	....	Galvanized.
1889.						
Oct. 31	.1744	.0239	66,392	....	....	Galvanized.
Oct. 31	.1744	.0239	66,391	....	....	Galvanized.
Oct. 25	.1073	.00902	72,049	....	....	Galvanized.
Oct. 22	.1740	.0238	66,849	....	....	Galvanized.
Oct. 22	.1070	.0090	64,444	....	....	Galvanized.
Nov. 1	.0800	.005027	69,032	35,810	27,775,000	Galvanized.
Nov. 4	.0805	.005090	68,697	15,718	23,530,000	Galvanized.
Nov. 7	.1091	.009348	62,594	40,648	26,492,000	Galvanized.
Nov. 8	.0800	.005027	70,000	35,785	25,380,000	Galvanized.
Nov. 12	.1050	.008659	66,870	23,100	24,400,000	Galvanized.
Nov. 13	.1050	.008659	67,210	41,570	27,330,000	Galvanized.
Nov. 14	.1050	.008659	67,300	.....	27,892,000	Galvanized.
Nov. 18	.1050	.008659	67,675	39,500	27,367,000	Galvanized.
Nov. 20	.1075	.009076	63,570	41,860	27,205,000	Galvanized.
Nov. 25	.1050	.008659	67,560	41,570	28,236,000	Galvanized.
Nov. 26	.0800	.00503	70,029	35,812	24,114,000	Galvanized.
Dec. 6	.0800	.00503	70,425	27,851	25,200,000	Galvanized.
Dec. 9	.0800	.00503	69,032	15,915	23,264,000	Galvanized.
Dec. 9	.080	.00503	69,630	19,894	24,946,000	Galvanized.
Dec. 12	.081	.00515	68,509	31,049	25,670,000	Galvanized.
Dec. 16	.1095	.009417	55,900	36,100	26,020,000	Galvanized.
Nov. 1	.175	.02405	68,398	....	....	Galvanized.
1890.						
Feb. 25	.133	.01389	70,395	38,700	25,193,000	Galvanized.
Feb. 27	.133	.01389	70,216	47,338	28,283,000	Galvanized.
March 10	.1334	.01397	69,929	47,144	28,917,000	Galvanized.
March 12	.1328	.01380	69,625	40,439	28,571,000	Galvanized.
March 17	.1327	.01380	70,430	47,287	26,090,000	Galvanized.
March 18	.1327	.01380	71,437	47,287	27,064,000	Galvanized.
Oct. 13	.1212	.0115	69,600	....	24,590,000	Galvanized.
Oct. 16	.1250	.01227	66,239	....	24,656,000	Galvanized.
Oct. 17	.1219	.01167	68,370	....	24,377,000	Galvanized.
Oct. 20	.1195	.0112	65,530	....	27,733,000	Galvanized.
Oct. 23	.1225	.0118	69,070	....	27,282,000	Galvanized.
Oct. 24	.1188	.01109	73,616	39,514	22,190,000	Galvanized.
Oct. 27	.1206	.0114	68,980	....	27,529,000	Galvanized.
Nov. 7	.1222	.01165	69,320	....	26,438,000	Galvanized.
Nov. 13	.1217	.0116	70,320	....	27,640,000	Galvanized.
Nov. 14	.1198	.01127	72,567	....	24,574,000	Galvanized.
Nov. 17	.1190	.01112	73,097	....	27,287,000	Galvanized.
Nov. 18	.1219	.01165	69,775	....	27,290,000	Galvanized.
Nov. 19	.1215	.01158	66,780	....	25,904,000	Galvanized.
Nov. 20	.1210	.0115	69,831	....	27,007,000	Galvanized.
Dec. 10	.1359	.01453	66,979	....	27,129,000	Galvanized.
Dec. 11	.1360	.01453	67,667	....	24,763,000	Galvanized.
Dec. 12	.1360	.01453	64,225	....	26,604,000	Galvanized.
1891.						
March 2	.1362	.01460	67,125	....	26,147,000	Galvanized.
March 3	.1360	.01453	68,357	....	26,580,000	Galvanized.
March 4	.1360	.01453	65,603	....	26,996,000	Galvanized.
March 4	.1360	.01450	69,045	....	28,680,000	Galvanized.
March 5	.1356	.01440	71,740	....	24,910,000	Galvanized.
March 5	.1358	.01450	67,180	....	27,130,000	Galvanized.

IRON WIRE TESTS.

Date.	Diameter.	Original Section. (Sq. in.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Modulus of Elasticity.	Remarks.
1891.						
March 6	.1357	.01450	67,177	....	29,070,000	Galvanized.
March 10	.1360	.01450	66,290	....	28,920,000	Galvanized.
March 12	.1372	.0148	66,490	....	28,660,000	Galvanized.
March 13	.1362	.0146	67,130	....	28,840,000	Galvanized.
March 16	.1362	.0146	67,813	....	27,730,000	Galvanized.
March 17	.1358	.0145	68,560	....	27,290,000	Galvanized.
March 18	.1357	.0144	66,240	....	28,164,000	Galvanized.
March 19	.1356	.0144	68,415	....	27,315,000	Galvanized.
March 20	.1365	.0146	67,860	....	28,653,000	Galvanized.
March 20	.1359	.0145	67,420	....	28,905,000	Galvanized.
March 26	.1354	.0144	67,570	....	29,397,000	Galvanized.
March 30	.1355	.0144	67,130	....	29,321,000	Galvanized.
April 1	.1362	.0146	65,067	....	28,513,000	Galvanized.
April 6	.1356	.0144	67,030	....	29,033,000	Galvanized.
April 8	.1356	.0144	67,030	....	28,792,000	Galvanized.
Oct. 12	.1602	.02016	47,975	....	22,214,000	Galvanized.
Oct. 16	.1358	.01448	66,142	39,906	28,867,000	Galvanized.
Oct. 16	.1360	.01453	67,325	34,282	28,716,000	Galvanized.
Oct. 19	.1360	.01453	74,208	37,035	28,329,000	Galvanized.
Oct. 23	.1360	.01453	66,636	37,789	30,392,000	Galvanized.
Oct. 24	.1380	.01496	62,044	....	28,270,000	Galvanized.
Oct. 28	.1044	.00856	88,548	48,828	29,537,000	Bright.
Oct. 31	.1044	.00856	80,604	58,175	29,326,000	Bright.
Nov. 4	.1030	.00833	62,168	40,565	28,609,000	
Nov. 5	.1028	.00830	62,410	40,723	28,449,000	
Nov. 7	.0803	.00506	87,475	39,097	26,902,000	
Nov. 5	.1042	.00853	87,716	39,366	28,883,000	Bright.
Nov. 3	.1021	.008187	69,376	41,283	27,982,000	Annealed.
Nov. 9	.0800	.00503	87,137	47,349	27,785,000	
Nov. 10	.0800	.005003	90,600	55,600	28,309,000	
Nov. 17	.1031	.00835	62,047	45,278	28,656,000	Annealed.
Nov. 23	.0796	.00498	61,892	43,807	29,665,000	Annealed.
Nov. 30	.1047	.00861	81,072	57,842	27,137,000	Annealed.
Dec. 2	.0799	.00501	81,372	31,512	28,250,000	Annealed.
Dec. 2	.0799	.00501	89,350	43,479	26,891,000	Annealed.
Dec. 3	.1040	.0085	80,990	35,080	28,782,000	Annealed.
Dec. 7	.0706	.003915	72,775	40,360	28,289,000	Annealed.
Dec. 9	.0710	.00396	70,216	39,907	28,734,000	Annealed.
Dec. 9	.0708	.00394	74,424	40,133	28,831,000	Annealed.
Dec. 10	.0710	.00390	70,216	39,907	26,349,000	Annealed.
Dec. 11	.0798	.00500	60,584	31,592	27,925,000	Annealed.
Dec. 14	.0788	.00487	63,155	32,398	34,932,000	Annealed.
Dec. 15	.0712	.00398	71,078	34,660	26,162,000	Annealed.
Dec. 16	.09112	.00652	82,502	38,665	27,806,000	
Dec. 16	.0915	.006576	81,818	51,402	27,109,000	
Dec. 18	.0707	.003926	72,087	40,246	28,524,000	
Dec. 18	.0710	.003959	72,742	50,010	27,940,000	
Dec. 21	.0712	.00398	69,822	49,730	27,661,000	
Dec. 22	.0710	.003959	74,000	44,959	28,027,000	
Dec. 23	.0710	.003959	71,480	39,907	31,931,000	
Dec. 23	.0709	.003948	71,861	40,020	28,300,000	
1892.						
March 10	.0920	.00665	80,930	50,840	28,520,000	Bright.
March 11	.0919	.00663	81,160	56,990	33,700,000	Bright.
March 11	.0920	.00665	77,920	38,810	27,075,000	Bright.
March 14	.0807	.00512	60,200	38,710	28,232,000	Annealed.
March 15	.0806	.00504	61,122	39,293	28,300,000	Annealed.
March 16	.0800	.00503	65,250	39,390	29,043,000	Annealed.
March 17	.0799	.00501	65,417	35,500	21,050,000	Annealed.
March 18	.0739	.00429	75,305	50,825	27,910,000	
March 21	.0712	.00398	81,125	59,970	27,906,000	Bright.
March 22	.0709	.00395	72,948	....	28,620,000	Bright.
March 25	.0702	.00387	72,342	56,324	27,931,000	Bright.
March 28	.0710	.00396	74,000	....	28,190,000	Bright.
March 29	.0710	.00396	74,000	44,960	27,725,000	Bright.
March 30	.0710	.00396	70,216	44,960	27,726,000	Bright.

IRON WIRE TESTS.

Date.	Diameter.	Original Section. (Sq. in.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Modulus of Elasticity.	Remarks.
1892.						
March 30	.0710	.00396	71,480	50,010	40,804,000	Bright.
March 31	.0712	.00398	69,822	39,683	21,582,000	Bright.
Oct. 31	.0621	.00303	125,460	70,572	28,536,000	Bright.
Oct. 28	.0622	.00304	134,100	62,530	27,655,000	Bright.
Nov. 2	.08075	.00512	87,869	55,650	27,543,000	Annealed.
Nov. 9	.1057	.00878	75,800	37,892	29,162,000	Bright.
Nov. 4	.0809	.0050	78,157	51,748	26,630,000	Annealed.
Nov. 7	.1013	.00806	69,700	39,332	28,716,000	Annealed.
Nov. 14	.1053	.00871	80,725	37,089	30,443,000	Bright.
Nov. 14	.1062	.00886	76,145	37,537	30,642,000	Bright.
Nov. 15	.1055	.0087	79,333	36,949	31,614,000	Bright.
Nov. 16	.1062	.00886	67,396	39,004	25,840,000	Bright.
Nov. 16	.1060	.00884	78,586	37,678	29,656,000	Bright.
Nov. 22	.1061	.00884	80,587	38,682	31,836,000	Bright.
Nov. 23	.1057	.00877	80,115	36,810	29,935,000	Bright.
Nov. 28	.1057	.00878	77,949	37,893	30,497,000	Bright.
Nov. 29	.1061	.00884	76,684	37,520	29,106,000	Bright.
Nov. 30	.1057	.00877	81,198	36,809	30,283,000	Bright.
Dec. 2	.1060	.00882	77,510	36,602	31,203,000	Bright.
Dec. 3	.1009	.0080	55,840	34,454	31,368,000	Annealed.
Dec. 6	.1009	.0080	57,029	32,078	25,505,000	Annealed.
Dec. 7	.1009	.0080	56,279	34,454	28,686,000	Annealed.
Dec. 13	.1661	.0217	70,748	51,734	21,734,000	Bright.
Dec. 13	.1646	.0213	72,043	53,574	26,854,000	Bright.
Dec. 14	.1664	.0217	70,493	52,421	24,589,000	Bright.
Dec. 14	.1663	.0217	70,578	52,485	21,206,000	Bright.
Dec. 15	.1659	.0216	70,918	52,738	23,999,000	Bright.
Dec. 16	.1668	.0219	69,289	53,040	19,321,000	Bright.
1893.						
March 29	.1218	.01165	70,119	24,460	32,079,000	Bright.
March 30	.1226	.0118	65,988	27,367	27,591,000	Bright.
March 31	.1221	.01171	68,153	27,586	30,520,000	Bright.
April 1	.1231	.01190	67,049	27,139	37,146,000	Bright.
April 3	.1223	.01175	67,552	24,261	26,442,000	Bright.
April 3	.1215	.01159	53,610	24,582	27,465,000	Bright.
April 7	.1228	.01184	67,533	27,272	31,353,000	Bright.
April 10	.1227	.01182	66,684	30,530	29,573,000	Bright.
April 10	.0794	.00495	66,041	42,210	28,530,000	Annealed.
April 12	.0795	.00503	64,221	39,666	26,710,000	Annealed.
April 13	.0800	.00503	66,149	43,470	27,193,000	Annealed.
April 14	.0733	.00423	83,070	65,108	28,383,000	Annealed.
April 17	.0800	.00503	66,149	43,470	27,193,000	Annealed.
April 18	.0798	.0050	66,480	41,788	27,252,000	Annealed.
April 20	.0802	.00505	64,879	41,372	26,375,000	Annealed.
April 20	.0798	.0050	66,149	43,370	28,377,000	Annealed.
Oct. 31	.1334	.01398	....	....	27,394,000	Annealed.
Nov. 1	.1355	.01442	46,116	....	20,956,000	Annealed.
Nov. 2	.1388	.01512	44,213	20,100	19,972,000	Annealed.
Nov. 3	.1350	.01431	47,034	22,566	21,366,000	Annealed.
Nov. 4	.1338	.01406	48,220	25,674	43,798,000	Annealed.
Nov. 6	.1337	.01404	47,723	21,644	44,614,000	Annealed.
Nov. 8	.1343	.01416	47,366	22,801	24,876,000	Annealed.
Nov. 10	.1341	.01412	48,005	25,560	23,810,000	Annealed.
Nov. 11	.1331	.01391	47,820	23,214	24,097,000	Annealed.
Nov. 14	.0625	.00307	58,670	37,157	33,384,000	Bright.
Nov. 16	.0612	.00294	61,360	....	24,947,000	Bright.
Nov. 20	.0612	.00294	71,558	38,754	27,602,000	Annealed.
Nov. 21	.0613	.00295	61,160	35,408	29,480,000	Annealed.
Nov. 25	.0627	.0030887	58,460	36,954	27,372,000	Annealed.
Nov. 27	.0615	.00297	60,672	41,574	29,075,000	Annealed.
Nov. 28	.0613	.00294	61,182	41,978	29,526,000	Annealed.
Dec. 6	.0680	.00363	49,701	36,622	23,287,000	Annealed.
Dec. 8	.0614	.00296	60,960	41,700	28,905,000	Annealed.
Dec. 11	.0616	.00298	60,560	41,440	28,804,000	Annealed.
Dec. 15	.0613	.00295	61,160	41,846	28,741,000	Annealed.
Dec. 30	.0616	.00298	60,565	35,064	25,571,000	Annealed.

COPPER WIRE TESTS.

Date.	Diameter.	Original Section. (Sq. in.)	Maximum Load. (Lbs. per sq. in.)	Elastic Limit. (Lbs. per sq. in.)	Modulus of Elasticity.	Remarks.
1887.						
Oct. 14	.135	.01431	30,740	....	....	Soft.
Oct. 14	.135	.01431	31,788	....	....	Soft.
Oct. 14	.105	.00866	31,200	....	....	Soft.
Oct. 14	.105	.00866	34,100	....	....	Soft.
Nov. 11	.105	.00866	33,953	....	....	Soft.
Nov. 11	.105	.00866	35,570	....	....	Soft.
Nov. 11	.072	.00407	46,671	....	....	Soft.
Nov. 11	.072	.00407	39,302	....	....	Soft.
1889.						
Oct. 18	.1378	.01491	60,350	22,800	14,198,000	Hard drawn.
Oct. 18	.0836	.005489	64,673	16,033	18,309,000	Hard drawn.
Oct. 21	.0836	.005489	52,649	....	18,590,000	Hard drawn.
Oct. 22	.0845	.005600	61,510	21,390	17,478,000	Hard drawn.
Oct. 25	.2036	.03256	66,959	....	....	Hard drawn.
Oct. 25	.0810	.00515	62,130	....	17,700,000	Hard drawn.
Oct. 31	.0818	.005255	52,899	19,029	16,404,000	Hard drawn.
Nov. 1	.2040	.03268	62,260	....	....	Hard drawn.
1890.						
March 24	.0855	.00574	58,173	27,867	18,553,000	Hard drawn.
March 27	.0859	.0058	58,620	29,310	19,016,000	Hard drawn.
March 31	.1657	.02156	53,051	37,098	18,928,000	Hard drawn.
April 6	.1343	.01437	57,050	27,140	18,389,000	Hard drawn.
April 9	.1345	.01421	56,300	28,150	18,320,000	Hard drawn.
April 14	.083	.0054	66,536	29,630	19,568,000	Hard drawn.
Oct. 28	.1349	.0143	62,830	....	20,134,000	Hard drawn.
Oct. 29	.1349	.0143	63,596	....	19,902,000	Hard drawn.
Nov. 3	.1349	.0143	61,780	....	19,990,000	Hard drawn.
Nov. 5	.1348	.0143	62,570	....	19,962,000	Hard drawn.
Nov. 21	.1662	.0217	58,449	....	21,329,000	Hard drawn.
Dec. 4	.1663	.0217	58,679	....	21,340,000	Hard drawn.
Dec. 5	.1663	.0217	56,144	....	21,112,000	Hard drawn.
Dec. 8	.1100	.0095	58,716	....	18,910,000	Hard drawn.
Dec. 9	.1099	.0095	51,034	....	20,214,000	Hard drawn.
1891.						
Oct. 26	.083	.0054	65,057	37,334	24,399,000	Hard drawn.
1894.						
March 26	.1625	.02074	35,729	13,742	13,572,000	Soft.
March 28	.1624	.02070	35,770	13,760	13,246,000	Soft.
April 2	.1615	.02050	36,640	12,990	16,416,000	Soft.

TESTS ON TORSION MACHINE.

Date.	Specimen.	Diameter in Inches.	Maximum Twisting Moment. (Inch Pounds.)	Maximum Outside Fiber Stress.	Shearing Modulus of Elasticity.	Number of Turns.	Distance between grips. (Inches.)	Angle of Twist for 3,600 inch pounds Twisting Moment.	Remarks.
1893.								Deg. Min.	
Nov. 9	Refined Iron.	2.03	84,240	51,285	12,471,000	4.00	72.10	0 — 29	
Nov. 15	Refined Iron.	2.03	66,960	40,646	12,576,000	1.25	71.20	0 — 29	
Nov. 21	Refined Iron.	2.03	70,200	41,743	11,372,000	3.50	70.50	0 — 32	
Nov. 22	Refined Iron.	2.03	72,000	43,834	10,960,000	2.30	72.10	0 — 34	
Nov. 23	Refined Iron.	2.03	61,920	36,820	11,393,000	2.80	71.80	0 — 34	
Nov. 24	Refined Iron.	2.03	68,760	40,887	11,360,000	2.50	71.30	0 — 32	
Dec. 14	Refined Iron.	2.03	78,120	46,453	12,871,000	2.80	69.30	0 — 27	
1894.									
March 26	Refined Iron.	1.30	22,320	52,127	11,436,000	14.60	71.75	3 — 15	
March 28	Refined Iron.	1.50	36,360	54,867	11,482,000	10.30	71.25	1 — 48	
March 30	Refined Iron.	1.33	45,360	50,852	12,359,000	6.70	71.75	1 — 25	
March 21	Refined Iron.	1.50	32,760	49,435	11,071,000	14.60	79.50	1 — 52	
1893.									
Nov. 3	Norway Iron.	2.00	72,360	46,065	11,406,000	16 50	70.40	....	
Nov. 6	Norway Iron.	2.02	74,970	46,600	13,215,000	16.00	72.00	....	
Nov. 13	Norway Iron.	2.03	72,000	43,757	12,902,000	14.00	71.30	....	
Dec. 11	Norway Iron.	2.02	74,520	46,321	12,247,000	17.00	70.40	....	
Dec. 12	Norway Iron.	2.02	72,000	45,837	12,738,000	14.25	69.80	....	
1894.									
Jan. 3	Norway Iron.	2.03	74,880	45,692	11,361,000	15.50	70.30	....	
Feb. 8	Norway Iron.	2.03	74,880	44,658	11,957,000	20.00	71.13	....	
March 12	Norway Iron.	2.03	79,560	48,437	11,554,000	16.00	70.20	....	
April 2	Burden's Best.	1.25	20,160	52,569	12,272,000	16.80	71.60	....	
1894.									
Jan. 30	Glendon Steel.	1.75	66,960	63,632	12,418,000	11.88	60.00	0 — 31	
March 14	Steel.	1.39	39,600	75,031	11,243,000	15.40	59.75	2 — 30	
March 16	Steel.	1.39	37,620	71,250	12,594,000	15.00	59.50	2 — 16	

ROPE TESTS.

Date.	Kind of Rope.	Size. Circumference in Inches.	No. of Strands.	No. of Yarns.	Feet per Pound.	Turns per Foot.	Method of Holding.	Location of Break.	Breaking Load in Lbs.	Condition.
1892.										
Nov. 29	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	4,575	Ends wet.
Nov. 30	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	2,117	Knot tied at center.
Dec. 1	Manila.	2	3	45	7.13	5.15	Eye Splice.	Splice.	4,109	Dry.
Dec. 3	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	4,723	Ends wet.
Dec. 5	Manila.	2	3	45	7.13	5.15	Bowline.	Knot.	2,555	Dry.
Dec. 5	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	5,271	Ends wet.
Dec. 6	Manila.	2	3	45	7.13	5.15	Half hitches.	Knot.	3,670	Dry.
Dec. 7	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	4,117	Ends wet.
Dec. 8	Manila.	2	3	45	7.13	5.15	Eye Splice.	Splice.	4,457	Dry.
Dec. 9	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center Splice.	3,998	Long splice at center.
Dec. 9	Manila.	2	3	45	7.13	5.15	Eye Splice.	Splice.	4,459	Dry. Splice tapered one yarn at a tuck.
Dec. 13	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	3,998	Dry.
Dec. 14	Manila.	3	3	93	4.3	4.1	Eye Splice.	Splice.	6,085	Dry.
Dec. 15	Manila.	3	3	93	4.3	4.1	Eye Splice.	Splice.	6,539	Dry.
1893.										
March 29	Manila.	3	3	93	4.3	4.1	Eye Splice.	Center.	9,134	Ends wet.
March 30	Manila.	3	3	93	4.3	4.1	Eye Splice.	Center.	9,755	Ends wet.
March 31	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	3,118	Ends wet.
April 1	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	4,435	Ends wet.
April 3	Manila.	6	4	180	....	....	Eye Splice.	Center.	21,655	Ends wet.
April 4	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	5,091	Ends wet.
April 5	Manila.	2	3	45	7.13	5.15	Eye Splice.	Center.	4,856	Ends wet.
April 10	Manila.	3	3	93	4.3	4.1	Eye Splice.	Splice.	8,845	Ends wet.
April 12	Manila.	3	3	93	4.3	4.1	Eye Splice.	Center.	9,489	Ends wet.
April 12	Manila.	4	3	....	....	....	Eye Splice.	Splice.	14,817	Ends wet.
April 12	Manila.	4	3	....	....	....	Eye Splice.	Splice.	14,664	Ends wet.
April 12	Manila.	6	4	180	....	....	Eye Splice.	Center.	24,171	Ends wet.
April 17	Manila.	4	3	....	....	....	Eye Splice.	Splice.	14,218	Ends wet.
April 19	Manila.	6	4	180	....	....	Eye Splice.	Center.	25,991	Ends wet.

ROPE TESTS.

Date.	Kind of Rope.	Size. Circumference in Inches.	No. of Strands.	Feet per Pound.	Turns per foot.	Method of Holding.	Location of Break.	Breaking Load in Lbs.,	Conditions.
1893.									
Oct. 24	Manila.	4.25	3	2.50	3.0	Eye Splice.	Splice.	16,067	Ends wet.
Oct. 24	Manila.	4.00	3	2.50	3.0	Eye Splice.	Splice.	14,501	Ends wet.
Oct. 26	Manila.	4.25	3	2.50	3.0	Eye Splice.	Splice.	14,062	Ends wet.
Oct. 28	Manila.	4.50	3	2.00	3.0	Ey Splice.	Splice.	13,854	Ends wet.
Oct. 31	Manila.	4.25	3	2.50	3.0	Eye Splice.	Splice.	14,358	Ends wet.
Nov. 3	Manila.	4.25	3	2.50	3.0	Eye Splice.	Splice.	16,687	Ends wet.
Nov. 8	Manila.	4.25	3	2.50	3.0	Eye Splice.	Splice.	14,773	Ends wet.
Nov. 10	Manila.	4.25	3	2.50	3.33	Eye Splice.	Splice.	13,058	Ends wet.
Nov. 13	Manila.	4.25	3	2.50	3.00	Eye Splice.	Splice.	15,439	Ends wet.
Nov. 15	Manila.	4.25	3	2.50	3.17	Eye Splice.	Splice.	14,021	Ends wet.
Nov. 17	Manila.	4.25	3	2.50	3.17	Eye Splice.	Splice.	14,709	Ends wet.
Nov. 22	Manila.	4.50	3	2.00	3.17	Eye Splice.	Splice.	13,426	Ends dry.
Nov. 24	Manila.	4.50	3	2.00	3.17	Eye Splice.	Splice.	12,338	Ends dry.
Nov. 25	Manila.	4.25	3	2.50	3.33	Eye Splice.	Splice.	12,593	Ends dry.
Nov. 29	Manila.	3.50	3	4.00	4.00	Eye Splice.	Splice.	5,882	Ends dry.
Dec. 11	Manila.	3.50	3	4.00	4.00	Eye Splice.	Splice.	7,860	Ends dry.
Dec. 11	Cotton.	2.75	3	6.10	6.00	Eye Splice.	Splice.	2,533	Ends dry.
Dec. 13	Manila.	3.50	3	4.00	4.00	Eye Splice.	Splice.	6,810	Ends dry.
Dec. 13	Cotton.	2.75	3	6.10	6.00	Eye Splice.	Center.	3,066	Ends dry.
Dec. 15	Cotton.	2.75	3	6.10	6.00	Eye Splice.	Splice.	2,476	Ends dry.
1894.									
Jan. 3	Cotton.	2.75	3	6.10	6.00	Eye Splice.	Splice.	2,755	Ends dry.
March 14	Manila.	4.25	3	2.50	3.33	Eye Splice.	Center.	8,564	Ends dry.
March 14	Manila.	4.25	3	2.50	4.50	Eye Splice.	Splice.	8,127	Ends dry.
March 16	Manila.	3.25	3	3.25	4.20	Eye Splice.	Splice.	7,712	Ends wet.
March 19	Manila.	3.25	3	3.25	4.20	Eye Splice.	Center.	8,024	Ends wet.
March 26	Manila.	4.00	3	2.50	3.41	Eye Splice.	Center.	9,296	Ends dry.
March 28	Manila.	5.00	3	1.30	3.00	Eye Splice.	Splice.	11,783	Ends dry.
April 4	Manila.	7.00	3	0.94	2.33	Eye Splice.	Splice.	20,041	Ends dry.

SPRUCE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per sq. in.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
3	2 x 12	15 — 0	Load at middle.	5,894	5,526	1,237,215	181	Crushing and tension.	
4	2 x 9	6 — 7½	Load at middle.	7,322	5,389	1,067,893	301	Crushing and tension.	
5	2 x 12	15 — 0	Load at middle.	5,586	5,237	....	174	Tension.	
5a	2 x 12	7 — 0	Load at middle.	8,982	....	....	....	Tension.	
6	2⅞ x 9	6 — 8	Load at middle.	7,586	4,082	938,453	230	Tension.	
7	3 x 9	4 — 0	Load at middle.	11,086	3,285	....	308	Tension.	
8	3 x 9	10 — 0	Load at middle.	6,086	4,508	....	170	Tension.	
9	3 x 9	15 — 0	Load at middle.	8,086	5,651	....	141	Tension and crushing.	
10	3⅛ x 12	20 — 0	Load at middle.	6,586	4,253	....	106	Tension.	
11	2⅛ x 13½	10 — 0	Load at middle.	9,585	3,787	....	208	Tension.	
12	3⅛ x 12	16 — 0	Load 4½ feet from end.	7,585	3,271	....	126	Tension.	
14	7 x 2	7 — 0	Load at middle.	1,944	8,748	....	105	Crushing.	Seasoned on wharf 4 years.
15	1½ x 6½	7 — 0	Load at middle.	4,785	7,562	....	304	Tension.	Seasoned on wharf 4 years.
16	3 x 9	6 — 8	Load at middle.	9,985	4,931	....	277	Tension.	
17	3 x 9	6 — 8	Load at 4 points 16 inches apart.	16,744	4,961	....	465	Tension.	
18	3.9 x 12	16 — 0	Load 4½ feet from end.	12,585	5,218	....	202	Tension.	
19	2 x 12	14 — 0	Load at middle.	4,404	3,854	1,482,645	138	Tension.	
20	2 x 12	14 — 0	Load at middle.	5,108	4,469	1,588,548	160	Tension.	
21	3⅛ x 12	14 — 0	Load at middle.	8,627	3,834	1,187,073	137	Tension.	
22	3⅛ x 12	14 — 0	Load at middle.	12,545	5,666	1,332,715	....	Tension and shearing.	
23	3⅛ x 12½	14 — 0	Load at middle.	6,917	2,995	897,961	108	Tension.	
24	3 x 11⅞	14 — 0	Load at middle.	8,927	5,442	1,572,470	....	Shearing.	
25	2 x 9⅞	14 — 0	Load at middle.	3,198	4,139	1,460,620	123	Crushing and tension.	
26	2⅜ x 12	14 — 0	Load at middle.	6,819	4,339	1,396,667	155	Tension.	
27	1⅛ x 10	14 — 0	Load at middle.	4,306	5,601	1,355,860	167	Tension.	
28	4⅛ x 12	18 — 0	Load at middle.	8,829	4,816	1,397,136	134	Tension.	
29	4 x 12½	18 — 0	Load at middle.	8,324	4,586	1,259,224	129	Tension.	
31	3⅛ x 12	18 — 0	Load at middle.	7,721	5,559	1,231,498	....	Crushing and shearing.	
35	6 x 12	18 — 0	Load at middle.	11,188	4,196	1,347,910	....	Shearing.	
36	2 x 11⅞	7 — 2	Load at middle.	7,870	3,599	....	....	Shearing and crushing.	
37	4 x 11⅞	12 — 0	Load at middle.	10,572	4,135	....	169	Tension.	
45	3⅛ x 11½	16 — 4	Load at middle.	8,072	4,436	....	133	Tension.	

SPRUCE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per Sq. In.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
46	$3\frac{1}{16}$ x 12	10 — 2	Load at middle.	13,772	4,746	.....	...	Shearing.	
49	$3\frac{3}{4}$ x $11\frac{3}{4}$	14 — 0	Load at middle.	12,076	5,878	.....	205	Tension and crushing.	
60	4 x 12	17 — 4	Distributed equally at 12 points.	26,000	7,448	1,461,039	406	Tension and crushing.	Seasoned in steam heat about six months, without load.
66	4 x 12	15 — 8	Load at middle.	14,576	7,211	1,336,162	230	Tension.	Seasoned in steam heat about six months, without load.
70	$4\frac{1}{8}$ x $12\frac{1}{4}$	17 — 4	Distributed equally at 12 points.	14,633	3,748	1,551,769	206	Tension.	
72	4 x $12\frac{5}{16}$	17 — 4	Distributed equally at 12 points.	11,333	3,252	1,228,563	177	Tension.	
90	6 x 12	17 — 4	Distributed equally at 12 points.	26,100	5,102	1,587,646	...	Shearing.	
196	$3\frac{1}{16}$ x $11\frac{15}{16}$	19 — 10	Center.	9,187	6,037	1,513,400	153	Crushing.	
197	$3\frac{3}{16}$ x 11	18 — 4	Center.	6,486	4,757	1,282,000	120	Tension.	
198	$3\frac{1}{4}$ x $11\frac{3}{4}$	17 — 6	Center.	10,178	5,993	1,529,000	170	Tension.	
199	$3\frac{1}{8}$ x $11\frac{1}{16}$	19 — 6	Center.	9,784	6,649	1,510,900	171	Tension.	
200	4 x $12\frac{1}{8}$	19 — 10	Center.	6,597	3,845	1,190,200	101	Tension.	
201	$3\frac{1}{16}$ x $11\frac{3}{4}$	18 — 4	Center.	10,958	5,941	1,490,200	191	Tension.	
202	$3\frac{3}{16}$ x $12\frac{1}{16}$	18 — 10	Center.	10,077	5,946	1,475,100	160	Tension.	
203	$3\frac{1}{16}$ x $11\frac{13}{16}$	19 — 10	Center.	11,184	7,626	1,850,600	189	Crushing.	
204	$3\frac{1}{16}$ x $11\frac{7}{16}$	18 — 8	Center.	10,970	7,066	1,470,400	188	Crushing.	
205	$3\frac{1}{16}$ x $12\frac{1}{16}$	18 — 8	Center.	8,082	4,727	1,208,000	128	Tension.	
297	4 x 12	15 — 5	Center.	6,025	2,923	1,010,000	97	Tension.	
298	$3\frac{1}{16}$ x 12	9 — 8	Center.	15,335	4,700	1,215,900	...		
299	$3\frac{1}{16}$ x 12	9 — 8	Center.	14,134	4,484	1,126,400	232	Tension.	
300	4 x 12	9 — 6	Center.	19,040	5,652	1,173,000	298	Tension.	
301	4 x $12\frac{1}{4}$	9 — 6	Center.	19,041	5,537	1,210,000	295	Tension.	
304	$4\frac{1}{8}$ x 12	15 — 0	Center.	8,475	3,852	1,466,801	...	Shearing.	
305	$4\frac{1}{16}$ x 12	15 — 0	Center.	9,779	4,515	1,345,555	152	Tension.	
307	$4\frac{1}{16}$ x 12	16 — 0	Center.	10,233	4,594	1,238,000	156	Tension.	
308	$4\frac{1}{8}$ x 12	16 — 0	Center.	12,186	5,735	1,466,700	179		
309	$3\frac{15}{16}$ x $12\frac{1}{8}$	16 — 0	Center.	9,283	4,618	1,067,328	141	Tension.	
311	$4\frac{1}{8}$ x 12	16 — 0	Center.	8,891	4,184	1,156,105	129	Tension.	
314	$3\frac{15}{16}$ x 12	16 — 0	Center.	6,670	3,442	978,731	102	Tension.	
316	4 x $11\frac{7}{8}$	16 — 0	Center.	11,885	6,068	1,290,315	184	Tension.	
317	$4\frac{1}{16}$ x 12	16 — 0	Center.	12,189	5,638	1,479,400	175	Tension.	
318	4 x $11\frac{7}{8}$	16 — 0	Center.	11,875	6,113	1,414,800	191	Tension.	

SPRUCE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per Sq. In.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
319	3⅛ x 12	16 — 0	Center.	12,386	6,393	1,470,900	201	Crushing.	
320	3⅛ x 11½	16 — 0	Center.	5,386	2,828	1,092,600	85		
321	3⅛ x 11⅛	16 — 0	Center.	13,086	8,120	1,899,800	...	Tension and shearing.	
322	4 x 12⅛	16 — 0	Center.	9,571	4,639	1,081,370	145	Tension.	
323	3⅛ x 12	15 — 0	Middle.	9,170	4,585	1,196,600	154	Tension.	
325	4 x 12⅛	16 — 0	Middle.	8,175	4,003	979,300	128	Tension.	
327	4 x 12	15 — 0	Middle.	4,665	2,187	890,660	74	.....	Cross-grained and knotty.
328	3⅛ x 11⅛	16 — 0	Middle.	12,375	6,522	1,701,500	203	Shearing.	
330	3⅛ x 12	15 — 0	Middle.	6,075	3,037	1,089,500	103		
333	4⅛ x 11⅛	15 — 0	Middle.	5,353	2,512	849,480	83		
336	4 x 12⅛	15 — 0	Middle.	7,961	3,655	1,002,400	124	Tension.	
344	3⅛ x 12⅛	15 — 0	Middle.	10,761	5,184	1,369,100	175	Tension.	
348	3⅛ x 11⅜	15 — 0	Middle.	13,162	6,652	1,689,600	217	Tension.	
349	3⅛ x 11⅛	15 — 0	Middle.	7,766	3,801	1,116,300	126	Tension at knot.	
351	3⅛ x 11⅛	15 — 0	Middle.	10,464	5,385	1,382,000	176	Crushing.	
353	3⅛ x 12	15 — 0	Middle.	11,978	5,989	1,253,900	200	Crushing.	
354	4 x 12⅛	16 — 0	Middle.	8,184	4,049	1,169,000	127	Tension.	
355	3⅛ x 11⅛	15 — 0	Middle.	7,760	3,893	1,233,400	126	Tension.	
356	3⅛ x 11⅛	15 — 0	Middle.	9,963	4,774	1,464,700	157	Tension.	
359	3 x 9⅛	17 — 0	Middle.	4,740	4,958	1,147,500	120	Compression and tension.	
363	4⅛ x 12⅛	15 — 0	Middle.	10,170	4,598	1,285,100	157	Compression and tension.	
365	3⅛ x 12⅛	17 — 0	Middle.	9,176	4,980	1,129,400	147		
366	3 x 9⅛	17 — 0	Middle.	5,540	5,793	1,411,200	141	Compression and tension.	
367	2⅞ x 9⅛	17 — 0	Middle.	1,630	1,869	1,211,000	47	Tension.	Cross-grained.
369	3⅛ x 12⅛	17 — 0	Middle.	9,876	5,217	1,373,000	157	Tension and compression.	
370	4 x 12	17 — 0	Middle.	10,789	5,732	1,408,700	170	.....	Wet stick.
372	3⅛ x 9⅛	12 — 0	2 points, each 2 feet from center.	3,722	1,794	854,080	94	Tension.	
373	3 x 9⅛	12 — 0	2 points, each 2 feet from center.	9,595	4,733	1,126,500	244	Tension and compression.	
374	2⅞ x 9⅛	12 — 0	2 points, each 2 feet from center.	10,767	5,673	1,593,000	289	Shearing.	
377	2⅞ x 9⅛	12 — 0	½ at center; ¼–3 ft. each from center.	4,626	2,722	1,072,200	128	Tension.	
378	3⅛ x 12⅛	15 — 6	2 points, each 2 feet from center.	17,259	6,252	1,720,000	277	Tension.	
380	1⅛ x 9⅛	12 — 0	Center.	4,216	5,086	1,361,000	176	Tension	

SPRUCE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per Sq. In.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
383	3 1/4 x 12 1/4	16 — 0	Center.	9,474	4,840	1,205,000	153		
384	2 7/8 x 10	11 — 6	Center.	9,360	6,739	1,537,000	244	Compression.	
385	2 7/8 x 10	11 — 6	Center.	5,005	3,604	1,082,000	131	Tension.	
387	4 1/8 x 12 1/4	16 — 0	Center.	9,869	4,735	1,666,600	149	Tension and compression.	
387a	4 x 11 3/4	16 — 0	Center.	11,956	6,232	1,442,800	191	Shearing, crushing, and tension.	
389	2 3/4 x 9 1/8	11 — 6	Center.	7,702	5,945	1,445,000	213	Tension and compression.	
392	3 1/4 x 12	16 — 0	Center.	15,813	9,036	2,132,400	284	Tension.	In laboratory 4 months.
395	3 11/16 x 11 13/16	12 — 0	Center.	8,132	3,339	1,055,500	138	Shearing.	
397	4 x 12	17 — 0	Center.	9,574	5,084	1,102,000	151	Tension.	
398	3 1/8 x 12	17 — 0	Center.	10,677	5,854	1,602,000	174	Tension.	
400	2 13/16 x 10 1/4	15 — 0	Center.	5,725	5,361	1,433,400	152	Tension.	
401	1 7/8 x 9 3/4	15 — 0	Center.	4,107	6,221	1,609,600	170	Tension.	
404	3 x 10	15 — 6	Center.	6,828	6,350	1,563,900	173	Tension.	
405	4 x 12	15 — 0	Center.	7,160	3,356	1,244,300	113	Shearing.	
407	4 1/8 x 11 7/8	16 — 0	Center.	8,660	4,287	1,099,300	134	Tension.	
408	4 x 12 1/16	16 — 0	Center.	8,762	4,248	1,280,300	136	Tension.	
409	3 1/16 x 12	15 — 6	Center.	6,152	3,127	985,950	102		
411	4 x 12	17 — 6	Equally at 12 points.	9,157	2,645	1,117,000	143	Tension.	
328	3 1/4 x 11 7/8	16 — 0	Center.	12,375	6,522	1,701,500	203	Shearing.	
374	2 7/8 x 9 3/4	12 — 0	2 points, 2 feet each side of center.	10,767	5,673	1,593,000	289	Shearing.	
387a	4 x 11 3/4	16 — 0	Center.	11,956	6,232	1,442,800	191	Shearing, tension, and crushing.	
395	3 11/16 x 11 13/16	12 — 0	Center.	8,132	3,339	1,055,500	138	Shearing.	
405	4 x 12	15 — 0	Center.	7,160	3,356	1,244,300	113	Shearing.	
414	2 1/8 x 10	15 — 0	Load at center.	5,200	4,902	1,270,500	138	Crushing at knot.	
415	3 x 9 1/8	16 — 0	Load at center.	3,700	3,723	1,105,700	98	Tension.	
416	2 5/8 x 9 3/8	15 — 6	Load at center.	7,900	8,087	1,548,400	215	Longitudinal shear and tension.	
417	4 1/2 x 11 3/4	14 — 0	Load at center.	12,100	5,139	1,622,500	182	Tension.	
421	3 1/8 x 11 1/4	15 — 0	Load at center.	12,000	6,010	1,318,000	199	Tension and longitudinal shear.	
422	3 1/8 x 11 1/2	14 — 0	Load at center.	13,200	6,182	1,304,700	217	Tension.	
423	4 x 12	14 — 0	Load at center.	13,260	5,762	1,213,100	207	Tension, crushing, and longitudinal shear.	
424	3 1/4 x 11 7/8	16 — 0	Load at center.	12,000	7,105	2,100,000	221	Tension.	
425	4 x 12	14 — 0	Load at center.	9,710	4,206	1,067,800	152	Tension.	
426	4 1/8 x 12	14 — 0	Load at center.	6,160	2,562	966,880	93	Tension.	
427	4 x 12 1/4	14 — 0	Load at center.	8,110	3,663	1,249,900	135	Tension.	

SPRUCE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per Sq. In.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
428	4 x 12	14 — 0	Load at center.	8,665	3,753	1,148,300	135	Tension.	
430	$2\frac{15}{16}$ x 10	14 — 0	Load at center.	4,440	4,217	1,377,600	127	Tension.	
431	$2\frac{3}{4}$ x 10	14 — 0	Load at center.	6,500	5,897	1,464,200	177	Tension.	
432	$2\frac{3}{4}$ x 10	14 — 0	Load at center.	5,500	4,991	1,156,400	150	Tension.	
433	$2\frac{13}{16}$ x $10\frac{1}{16}$	14 — 0	Load at center.	2,925	2,542	896,800	78	Tension.	
434	$2\frac{1}{16}$ x 10	14 — 0	Load at center.	7,020	6,525	1,819,900	196	Tension.	
435	$2\frac{3}{4}$ x 10	14 — 0	Load at center.	4,990	4,518	1,180,300	136	Tension.	
436	$2\frac{3}{4}$ x $9\frac{13}{16}$	14 — 0	Load at center.	5,120	4,830	1,242,800	139	Tension.	
438	$2\frac{3}{4}$ x $9\frac{3}{8}$	14 — 0	Load at center.	6,400	5,969	1,358,100	177	Tension.	
439	$2\frac{3}{4}$ x 10	14 — 0	Load at center.	6,000	5,467	1,263,700	164	Tension.	
441	$2\frac{3}{4}$ x 10	14 — 0	Load at center.	8,080	7,347	1,732,800	220	Tension.	
442	$1\frac{15}{16}$ x $9\frac{1}{16}$	11 — 0	Load at center.	4,130	4,519	1,368,000	166	Tension.	
443	4 x 12	14 — 0	Load at center.	10,760	4,780	1,129,800	172	Tension.	
444	4 x 12	14 — 0	Load at center.	10,000	4,495	1,238,200	163	Tension.	
445	$3\frac{15}{16}$ x 12	14 — 0	Load at center.	7,875	3,673	1,327,600	133	Longitudinal shear and tension.	
446	4 x 12	14 — 0	Load at center.	10,400	4,633	1,286,800	167	Tension.	
448	$4\frac{1}{16}$ x $12\frac{1}{16}$	14 — 0	Load at center.	10,800	4,639	1,236,400	167	Tension.	
449	$3\frac{15}{16}$ x 12	14 — 0	Load at center.	8,500	3,929	1,213,000	142	Tension.	
450	$4\frac{1}{16}$ x $11\frac{7}{8}$	14 — 0	Load at center.	10,400	4,658	1,160,900	166	Longitudinal shear and tension.	
456	$7\frac{13}{16}$ x $12\frac{1}{16}$	19 — 0	Load at center.	14,000	4,098	1,267,000	113	Tension.	
457	$7\frac{3}{4}$ x 12	19 — 0	Load at center.	14,750	4,456	1,176,700	121	Tension.	
458	$7\frac{3}{4}$ x 12	19 — 0	Load at center.	16,950	5,216	1,440,000	139	Tension.	

YELLOW PINE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per Sq. In.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
30	3 x 13 1/8	14 — 0	Load at center.	15,158	6,614	1,937,025	...	Shearing.	
32	4 1/16 x 12 5/16	18 — 0	Load at center.	13,751	7,383	1,733,976	...	Tension, crushing, and shearing.	
33	3 1/8 x 12 1/4	18 — 0	Load at center.	9,832	5,386	1,793,923	...	Shearing.	
47	3 x 13 3/8	14 — 0	Load at center.	19,574	8,696	2,386,096	359	Crushing.	
50	4 x 14 1/16	21 — 0	Load at center.	12,875	5,914	1,256,286	...	Shearing.	
53	3 1/4 x 14	24 — 6	Load at center.	10,076	7,206	1,784,426	179	Tension, crushing, and shearing.	
54	3 x 12 1/8	24 — 0	Load at center.	9,576	9,380	2,110,821	203	Crushing.	
56	3 1/4 x 14	15 — 4	Load at center.	10,572	4,764	1,490,396	185	Tension.	
57	2 1/8 x 12	19 — 2	Load at center.	8,472	6,950	1,444,521	182	Tension.	
59	9 x 13 3/8	24 — 0	Load at center.	21,083	5,352	1,417,793	133	Tension and crushing.	
62	4 1/8 x 12 1/8	19 — 10	Load at center.	15,461	9,102	2,037,939	237	Crushing.	
63	4 1/16 x 12 5/16	20 — 0	Load at center.	14,073	8,145	1,599,339	211	Tension.	
64	4 1/8 x 12 1/4	19 — 10	Load at center.	10,573	6,098	1,917,976	161	Tension.	
65	4 x 12 1/4	19 — 8	Load at center.	11,573	6,782	1,966,717	183	Crushing.	
67	4 1/8 x 12	18 — 6	Load at center.	13,374	7,277	1,787,610	196	Tension.	
68	4 x 12 1/8	19 — 9	Load at center.	17,676	10,872	2,381,685	278	Tension.	
69	3 7/8 x 14	20 — 0	Load at center.	6,675	3,963	1,169,298	115	Crushing.	
71	4 1/8 x 12	18 — 2	Load at center.	16,074	8,248	1,512,192	227	Tension.	
74	4 x 12	20 — 0	Load at center.	11,071	7,004	1,628,134	175	Tension.	
75	4 x 11 3/8	19 — 9	Load at center.	13,771	9,391	1,850,667	233	Tension.	
76	4 1/8 x 12 1/16	17 — 4	Load equally distributed at 12 points.	15,825	4,207	1,344,083	233	Tension.	
77	4 1/8 x 12	17 — 4	Load equally distributed at 12 points.	37,325	10,286	2,123,154	551	Tension.	
78	4 x 12 1/8	22 — 10	Load at center.	7,172	4,845	1,455,308	109		
79	4 x 12	19 — 8	Load at center.	....	....	2,087,583	...		
81	4 1/8 x 12 1/4	17 — 4	Load equally distributed at 12 points.	16,025	4,349	1,162,467	238	Tension.	
82	4 x 12	19 — 8	Load at center.	15,571	9,671	1,607,336	246	Tension.	
84	4 1/8 x 12 1/4	21 — 4	Load at center.	11,374	6,985	1,501,854	167		
85	4 x 11 3/8	20 — 6	Load at center.	16,874	11,360	2,246,154	271	Tension.	
87	4 x 12 1/4	21 — 4	Load at center.	11,272	7,335	1,535,647	175	Tension.	
88	6 x 12 1/4	20 — 4	Load at center.	15,283	6,112	1,613,012	161	Tension.	
91	4 x 12	19 — 10	Load at center.	18,074	11,303	2,223,795	282	Tension and shearing.	
92	6 x 12	6 — 5	Load at center.	38,090	5,092	....	397		
144	4 1/8 x 12	21 — 0	Load at center.	9,433	6,012	1,628,100	145	Tension.	
145	4 1/8 x 12 1/8	19 — 3	Load at center.	11,201	6,400	1,472,000	191	Tension.	
146	4 x 12	19 — 4	Load at center.	13,341	8,060	1,839,700	206	Tension.	
147	4 x 12	19 — 2	Load at center.	16,748	10,032	2,286,000	...	Shearing.	
216	4 1/8 x 12 1/4	15 — 8	Load at center.	15,453	7,040	1,557,300	...	Crushing and Shearing.	

YELLOW PINE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per Sq. In.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
218	4½ x 12⅛	15 — 6	Load at center.	15,613	7,484	2,010,300	244	Crushing and tension.	
219	4½ x 12⅛	15 — 6	Load at center.	16,632	7,427	1,623,800	244	Tension.	
220	4⅛ x 12½	15 — 6	Load at center.	17,710	7,982	1,775,100	265	Tension.	
221	4⅛ x 12 1/16	16 — 0	Load at center.	16,330	7,836	1,931,200	248	Tension.	
222	4⅛ x 12½	16 — 0	Load at center.	18,515	8,884	1,786,000	285	Tension.	
223	4 x 12	17 — 0	Load at center.	13,492	7,167	1,638,500	212	Crushing.	
224	3 1/16 x 11 1/16	17 — 0	Load at center.	16,426	8,958	1,938,900	264	Tension.	
225	4⅛ x 12	15 — 6	Load at center.	18,705	8,786	1,729,900	285	Tension.	
226	4⅛ x 12	15 — 6	Load at center.	16,594	7,794	1,611,200	253	Tension.	
252	3 1/16 x 11 1/16	17 — 0	Load at center.	11,006	6,002	1,271,000	177	Tension.	
254	4 x 12	16 — 0	Load at center.	15,226	7,613	1,617,700	240	Tension.	
255	4 1/16 x 12⅜	15 — 6	Load at center.	19,425	7,975	2,214,400	267	Crushing.	
257	4½ x 12⅛	16 — 0	Load at center.	17,424	8,031	1,789,800	256	Crushing.	
258	4 1/16 x 12	16 — 0	Load at center.	18,319	8,256	1,830,000	260	Tension.	
261	4 1/16 x 12	15 — 0	Load at center.	17,818	7,978	1,989,700	268	Tension.	
324	3½ x 12½	15 — 0	Load at center.	12,510	6,002	1,719,500	206	Shearing.	
326	4 x 12⅛	16 — 0	Load at center.	14,011	6,862	1,980,600	219	Tension.	
329	4½ x 12½	15 — 0	Load at center.	23,324	9,971	1,845,600	340	Tension.	
331	3⅛ x 11⅛	15 — 0	Load at center.	13,709	6,774	1,619,800	225	Tension.	
332	4 x 13½	15 — 0	Load at center.	21,733	8,356	2,109,600	310	Shearing.	
334	3⅛ x 13	15 — 0	Load at center.	17,400	7,105	1,586,600	259	Tension.	
335	4 x 12	15 — 0	Load at center.	16,228	7,686	1,911,400	257	Shearing.	
339	4 x 11⅜	16 — 6	Load at center.	15,737	8,373	2,128,800	250	Tension.	
342	4 1/16 x 12⅛	16 — 0	Load at center.	9,616	4,502	1,380,500	142	Tension.	
346	4 x 11⅞	16 — 0	Load at center.	16,227	8,284	1,857,800	256	Tension.	
347	4 x 12	17 — 0	Load at center.	13,536	7,191	2,041,000	211	Tension.	
350	4 x 12	15 — 0	Load at center.	19,212	8,912	1,790,500	299	Tension.	
352	4⅛ x 12⅛	17 — 0	Load at center.	18,238	9,087	2,059,600	271	Shearing.	
357	4⅛ x 12⅜	16 — 0	Load at center.	22,546	10,278	2,595,600	331	Tension and compression.	
358	4⅛ x 12½	17 — 0	Load at center.	20,825	10,371	2,137,340	312	Tension and compression.	
360	3 x 10	15 — 0	Load at center.	12,071	10,864	2,122,000	302	Tension.	
361	3 x 10	15 — 0	Load at center.	7,264	6,485	1,632,700	179	Tension.	
362	3 x 9⅞	15 — 0	Load at center.	8,467	7,815	1,833,700	214	Shearing.	
364	4 x 12½	15 — 0	Load at center.	15,208	6,879	1,667,500	237	Tension.	
368	4 x 12⅛	15 — 0	Load at center.	17,714	8,133	1,899,100	276	Tension.	
376	3⅞ x 11⅛	15 — 0	Load at center.	14,712	7,388	1,800,300	246	Tension.	
381	3⅛ x 11⅛	15 — 0	Load at center.	15,201	7,761	1,566,400	258	Tension and shearing.	

YELLOW PINE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Intensity of Shear in Lbs. per Sq. In.	Manner of Breaking.	Remarks.
	Inches.	Ft. In.		Lbs.					
382	4 x 12¼	15 — 0	Load at center.	17,525	7,803	1,882,700	269	Compression.	
386	4 x 12	16 — 0	Load at center.	12,110	6,055	1,310,000	191	Tension.	
388	4 x 12¼	16 — 0	Load at center.	10,534	5,059	1,658,800	162	Shearing and tension.	
390	4 x 12⅛	15 — 0	Load at center.	22,100	10,147	2,234,800	342	Shearing.	
391	4⅛ x 12	17 — 0	Load at center.	18,391	9,474	2,068,200	279	Tension.	
394	4⅛ x 12¼	16 — 0	Load at center.	19,713	8,902	1,996,400	286	Shearing.	
396	3⅛ x 12	20 — 0	Load at center.	10,296	7,354	1,889,000	186	Tension.	
396A	3⅛ x 12¼	8 — 6	Load at center.	25,827	7,392	2,217,000	445	Shearing.	
399	4⅛ x 12¼	16 — 0	Load at center.	8,602	3,828	1,306,000	124	Tension.	
402	4⅛ x 12 1/16	15 — 0	Load at center.	15,192	6,303	1,542,000	215	Tension.	
403	4⅛ x 12⅛	15 — 0	Load at center.	10,886	4,636	1,058,200	158	Tension.	
410	3⅛ x 12⅛	15 — 0	2 points, 2 feet each side of center.	18,590	6,304	1,733,400	297	Tension.	
412	4⅛ x 12¼	14 — 0	2 points, 2 feet each side of center.	15,865	4,627	1,774,100	237	Shearing.	
413	3⅛ x 12¼	15 — 0	2 points, 2 feet each side of center.	14,852	5,069	1,778,900	236	Tension.	
418	4 x 12	14 — 0	Load at center.	20,500	9,064	2,278,500	326	Tension.	
419	4 x 12	16 — 0	Load at center.	12,850	6,541	1,664,800	207	Crushing at top and shearing above neutral axis.	
420	4 x 12	14 — 6	Load at center.	14,000	6,442	1,684,400	225	Tension.	
429	4 x 12	14 — 0	Load at center.	15,600	6,759	1,498,500	244	Tension, compression, and longitudinal shear.	
437	6 x 16⅛	17 — 6	Load at center.	38,000	7,407	1,777,700	289	Tension and shear.	
440	4 x 12	16 — 0	Load at center.	19,500	9,908	1,778,400	312	Tension.	
447	3⅛ x 12¼	18 — 0	Load at center.	13,900	7,908	1,672,900	227	Tension.	
451	4 x 12⅛	18 — 6	Load at center.	9,350	5,446	2,013,200	151	Longitudinal shear and tension.	
452	4⅛ x 12 1/16	14 — 0	Load at center.	15,750	6,570	1,704,900	240	Tension and longitudinal shear.	
453	4 x 12	14 — 0	Load at center.	13,000	5,800	1,804,000	209	Tension.	
454	4⅛ x 12	19 — 0	Load at center.	12,000	6,848	1,603,800	182	Tension and compression.	
455	4⅛ x 12	16 — 0	Load at center.	16,750	8,200	1,656,000	259	Tension.	

NOTE. — Yellow Pine Beams that sheared are given in a separate table on page 173.

KILN-DRIED WESTERN WHITE PINE.

No. of Test.	Depth and Width.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Remarks.
	Inches.	Ft. In.		Lbs.			
206	$2\frac{1}{16}$ x $13\frac{3}{8}$	15 — 5	Center.	9,325	7,014	1,505,000	
207	2 x $12\frac{5}{8}$	13 — 0	Center.	8,814	6,432	1,193,000	
208	$2\frac{1}{16}$ x $12\frac{5}{16}$	15 — 0	Center.	3,420	2,836	752,300	
210	$2\frac{1}{16}$ x $11\frac{3}{4}$	15 — 0	Center.	4,518	4,284	1,241,400	
212	$2\frac{1}{16}$ x 13	15 — 6	Center.	6,120	4,898	1,099,300	
213	$2\frac{1}{16}$ x $13\frac{1}{16}$	15 — 6	Center.	....	....	1,276,300	
214	2 x $12\frac{7}{8}$	15 — 6	Center.	7,420	6,430	1,166,000	
237	$2\frac{3}{32}$ x $12\frac{1}{16}$	15 — 4	Center.	8,225	6,478	1,231,000	

HEMLOCK.

No. of Test.	Depth and Width.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Remarks.
	Inches.	Ft. In.		Lbs.			
154	$3\frac{1}{8}$ x $11\frac{5}{8}$	15 — 0	Center.	6,449	3,965	870,960	Nos. 154–160 are Eastern hemlock, seasoned about one year. The remainder of the hemlock tests are from hemlock cut in Vermont, June, 1886; first growth grown on high ground; sawed September 25, 1886; received at Institute November 15, 1886; tested December 2, 1886, to March 9, 1887.
155	$3\frac{1}{8}$ x 10	14 — 8	Center.	4,648	4,007	971,710	
156	$2\frac{5}{8}$ x $9\frac{3}{4}$	12 — 9	Center.	4,425	3,716	750,400	
157	$3\frac{1}{16}$ x $10\frac{1}{4}$	11 — 10	Center.	3,223	2,381	770,900	
158	$3\frac{1}{16}$ x $10\frac{5}{16}$	14 — 0	Center.	4,137	3,151	735,800	
159	3 x $9\frac{1}{8}$	13 — 6	Center.	2,939	2,570	833,000	
160	$2\frac{5}{8}$ x $11\frac{1}{2}$	12 — 8	Center.	9,433	5,911	1,086,600	
177	$4\frac{1}{8}$ x 12	15 — 8	Center.	9,605	4,560	1,081,100	
178	4 x 12	17 — 0	Center.	5,502	2,923	821,990	
179	$4\frac{1}{8}$ x $11\frac{5}{8}$	15 — 8	Center.	3,192	1,531	688,960	
180	4 x $12\frac{1}{4}$	15 — 6	Center.	4,584	2,175	926,560	
181	4 x $11\frac{5}{8}$	15 — 8	Center.	5,133	2,539	758,390	
182	4 x 12	15 — 6	Center.	11,073	5,363	1,296,600	
183	4 x 12	15 — 6	Center.	13,274	6,499	1,269,800	
184	$3\frac{7}{8}$ x $11\frac{7}{8}$	15 — 8	Center.	9,964	5,142	1,075,600	
185	$3\frac{7}{8}$ x $11\frac{5}{8}$	17 — 2	Center.	3,679	2,059	412,670	
186	$3\frac{5}{8}$ x $11\frac{1}{8}$	15 — 8	Center.	12,488	6,535	1,327,200	
114	$7\frac{3}{8}$ x $10\frac{1}{2}$	20 — 4	Center.	19,244	8,243	2,011,188	Yellow birch, N. H.
120	$7\frac{1}{4}$ x $10\frac{1}{2}$	19 — 6	Center.	16,150	7,627	1,583,201	Yellow birch, N. H.
127	3 x 10	13 — 6	Center.	14,965	12,122	....	N. H. ash, seasoned two years.

WHITE PINE BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Breaking Center Load in Lbs.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Remarks.
	Inches.	Ft. In.				
94	3 x 11¼	15 — 8	5,088	3,613	924,252	
95	3 x 13	14 — 0	12,588	7,251	1,280,832	Pattern stock. Clear piece seasoned three years.
96	3 x 13	16 — 6	9,088	5,324	1,072,889	
97	3 x 11	15 — 8	6,088	4,729	978,256	
98	2⅞ x 9⅞	16 — 0	6,088	6,415	1,234,880	
99	2⅞ x 13	15 — 6	5,988	3,438	1,020,390	
100	3 x 9⅞	16 — 0	4,288	4,330	1,165,937	
102	3 x 10⅞	15 — 6	4,790	3,855	999,190	
103	3 x 11	16 — 6	6,588	5,390	1,242,649	
104	3 x 11¼	15 — 6	5,088	3,739	931,760	
128	6 x 12	19 — 10	12,922	5,340	1,380,660	
129	6 x 12	19 — 8	15,060	6,170	1,565,000	
130	6 x 12⅛	19 — 8	12,340	4,954	1,222,100	
131	6 x 12	19 — 10	13,023	5,380	1,307,900	
132	6 x 12	19 — 10	6,231	2,575	1,103,500	
133	6 x 12	19 — 8	12,912	5,290	1,297,000	
134	6 x 12	20 — 0	11,254	4,689	1,345,700	
137	6 1/16 x 12 1/16	19 — 8	13,650	5,478	1,367,700	
138	6 x 12	19 — 9	14,010	5,765	1,247,100	
140	6 x 12	19 — 9	9,761	4,016	1,105,600	
244	4⅜ x 12 3/16	16 — 0	10,179	4,300	948,600	
245	4⅛ x 12⅛	15 — 6	12,984	5,620	1,271,000	
247	4 1/16 x 10⅛	15 — 8	6,770	3,638	1,111,900	
248	4⅛ x 12⅛	15 — 8	7,790	3,549	1,057,300	
279	4 x 12⅛	15 — 6	9,085	4,222	1,084,000	
280	4 x 12⅛	15 — 6	7,575	3,521	854,300	
281	3⅞ x 12 1/16	15 — 0	12,070	5,547	1,281,000	
282	3 15/16 x 12 1/16	15 — 0	8,660	3,998	1,053,000	
283	3 15/16 x 12⅛	15 — 0	7,182	3,285	970,300	
284	4 x 12⅛	15 — 0	5,685	2,456	873,300	
285	3 15/16 x 12 1/16	15 — 6	6,385	3,031	901,500	
286	3⅞ x 12 1/16	15 — 6	11,791	5,449	1,258,700	
287	4 x 12 1/16	15 — 6	8,265	3,802	1,049,500	
288	3⅞ x 12 1/16	15 — 6	11,272	5,353	1,295,382	
289	3⅞ x 12 1/16	15 — 6	5,671	2,806	825,300	
296	4 x 12 1/16	15 — 6	5,571	2,563	727,200	
315	3⅞ x 12	16 — 0	7,165	3,820	1,158,411	

WHITE OAK BEAMS.

No. of Test.	Width and Depth.	Distance between Supports.	Manner of Loading.	Breaking Load.	Modulus of Rupture in Lbs. per Square Inch.	Modulus of Elasticity in Lbs. per Square Inch.	Remarks.
	Inches.	Ft. In.		Lbs.			
48	6 x 12	19 — 6	Load at middle.	13,776	5,596	1,766,839	
51	4 1/8 x 14 3/8	15 — 6	Load at middle.	19,076	6,060	1,240,728	
55	3 x 13 1/4	13 — 8	Load at middle.	10,671	4,984	853,098	
80	4 x 12	18 — 0	Load at middle.	13,371	7,659	1,307,180	
109	4 x 10 1/2	15 — 4	Load at middle.	8,421	5,530	823,000	Nos. 109–112. Lumber cut in Ohio in the winter of 1884; tested in spring of 1885.
110	6 x 12 1/4	15 — 8	Load at middle.	17,834	5,586	1,227,666	
111	3 x 9	15 — 6	Load at middle.	2,821	3,240	1,134,498	
112	4 x 12	19 — 0	Load at middle.	8,783	5,214	1,057,378	
113	6 3/8 x 12 1/2	19 — 4	Load at middle.	15,104	5,494	744,774	Nos. 113–125. Lumber was cut in Pennsylvania in the winter of 1884–85; tested in spring of 1885.
115	4 x 12	19 — 6	Load at middle.	7,885	4,805	1,607,910	
116	6 x 12	20 — 0	Load at middle.	20,098	8,374	1,666,844	
117	4 x 12	17 — 0	Load at middle.	10,546	5,603	973,213	
118	4 x 12	19 — 6	Load at middle.	8,080	4,924	979,930	
119	4 x 12	16 — 0	Load at middle.	12,360	6,180	1,343,768	
122	4 x 12	19 — 0	Load at middle.	5,953	3,535	672,724	
123	4 x 12	19 — 0	Load at middle.	10,082	5,986	1,130,217	
125	4 x 12	19 — 9	Load at middle.	10,269	6,338	1,115,578	
149	2 5/8 x 11 1/2	15 — 10	Load at middle.	6,287	4,713	878,900	
150	3 x 11 1/2	17 — 6	Load at middle.	7,000	5,324	889,000	
151	4 x 12 7/8	16 — 8	Load at middle.	9,231	4,661	800,870	Ohio white oak.
152	4 x 10 1/2	17 — 9	Load at middle.	9,432	6,519	1,544,600	
153	3 1/8 x 12 1/2	18 — 0	Load at middle.	9,122	6,302	1,143,900	
168	3 1/8 x 11 1/8	20 — 0	Load at middle.	11,474	7,482	1,464,500	Tests Nos. 168–176, inclusive, were made on white oak from Ohio; sawed latter part of August, 1886; received at Institute October 11, 1886; tested October 15, 1886, to November 30, 1886.
169	4 x 11 1/8	19 — 8	Load at middle.	9,275	5,821	1,141,900	
171	3 1/2 x 12 7/16	19 — 4	Load at middle.	9,372	5,485	972,200	
172	3 1/8 x 11 1/8	17 — 8	Load at middle.	7,501	4,411	1,059,600	
173	4 x 12	19 — 8	Load at middle.	8,971	5,513	1,777,500	
174	4 x 11 1/8	20 — 0	Load at middle.	12,274	7,834	1,465,800	
175	4 1/16 x 11 1/8	16 — 0	Load at middle.	11,231	5,706	946,470	
176	4 x 11 1/8	17 — 8	Load at middle.	15,043	8,850	1,735,800	
259	5 x 12	15 — 6	Load at middle.	16,169	6,266	990,300	Nos. 259–269 are selected oak beams from Ohio, straight-grained, and nearly free from knots.
260	5 1/8 x 12 1/8	13 — 6	Load at middle.	15,138	4,832	813,400	
262	5 1/8 x 12 1/2	17 — 0	Load at middle.	14,994	6,040	1,134,000	
264	5 1/16 x 10 7/16	13 — 6	Load at middle.	14,720	6,808	1,089,000	
265	5 x 12 1/8	9 — 10	Load at middle.	26,088	6,281	861,200	
269	4 1/8 x 12 1/8	9 — 6	Load at middle.	29,788	7,107	953,800	Green lumber.

TIME TESTS.

The following is a record of the time tests made at the Institute, and at the close will be found a statement in regard to the proper value of modulus of elasticity for use in computing deflections.

TIME TEST NO. 1.

Spruce from Maine received at the Institute October 30, 1885. All the beams when received were green lumber, except F, which was seasoned on the wharf about six months. Beams A, B, C, D, E, and F were seasoned under a center load in the laboratory in steam heat from November 10, 1885, to May 8, 1886. Beams G, H, and I were seasoned in the same room without load; span = 20 feet for all the beams under load.

Beam.	A (164).	B (163).	C (162).	D (161).	E (169).	F (168).
Description of lumber	Clear.	Knotty.	Knotty	Clear.	Clear.	Clear.
Dimensions { original	4″ x 12″	4″ x 12″	4″ x 12″	4″ x 12″	6″ x 12″	6″ x 12″
Dimensions { final	3¾″ x 11¾″	4″ x 11¾″	3¾″ x 11¾″	3¾″ x 11¾″	5¾″ x 11⅝″	5⅝″ x 11¾″
Maximum fiber stress, lbs. per square inch { with weight of beam	1,078	1,076	1,074	1,070	1,133	1,136
Maximum fiber stress, lbs. per square inch { without weight of beam	1,003	1,003	1,003	1,003	1,057	1,051
Deflection, load first applied	0.5488″	0.6355″	0.7675″	0.6108″	0.7188″	0.5454″
Deflection, at end of test	1.0164″	1.4707″	1.5154″	1.3734″	1.2667″	0.3151″
E (immediate)	1,462,200	1,262,900	1,045,700	1,314,000	1,175,000	1,540,000
E (final)	789,000	546,000	529,000	584,000	667,000	2,666,000
Modulus of rupture, lbs. per square inch { with weight of beam	6,574	7,260	5,007	6,066	6,779	8,574
Modulus of rupture, lbs. per square inch { without weight of beam	6,500	7,187	4,937	6,000	6,708	8,500
Weight per cubic foot at beginning, lbs.	35.5	34.9	33.6	31.9	34.1	35.4
Weight per cubic foot at end, lbs.	27.1	28.1	25.5	25.7	28.2	29.6
Date of testing	May 11, 1886.	May 11, 1886.	May 10, 1886.	May 10, 1886.	May 14, 1886.	May 13, 1886.
E (after seasoning), lbs. per square inch of final section	1,866,900	1,509,500	1,367,300	1,625,500	1,737,400	1,718,300

Average E (immediate) = 1,300,000. Average E (final) = 963,500. Average modulus of rupture, beams under load, = 6,710.
All quantities in the above table, except the last, were calculated by using the original section.

TIME TEST NO. I. — *Continued.*

Beam.	G (165).	H (166).	I (167).
Description of lumber	Clear.	Clear.	Knotty.
Dimensions . . . { original	4″ x 12″	4″ x 12″	4″ x 12″
Dimensions . . . { final	3¾″ x 11⅝″	3¾″ x 12″	4″ x 12″
Modulus of rupture, lbs. per square inch { with weight of beam	....	....	....
Modulus of rupture, lbs. per square inch { without weight of beam	6,525	7,187	5,012
Weight per cubic foot at beginning, lbs.	....	....	....
Weight per cubic foot at end, lbs.	27.3	27	27.2
Date of testing	May 11, 1886.	May 12, 1886.	May 12, 1886.
E (after seasoning), lbs. per square inch of final section	1,603,700	1,748,900	1,457,000

Average E (final section), beams without load . . . 1,603,200
Average modulus of rupture (original section) . . . 6,508

TIME TESTS FOR SHORT PERIODS OF TIME.

No.	Depth and Width.	Span.	Original Modulus of Elasticity.	Total Increased Deflection.	Modulus of Rupture.	Description of Test.
	Inches.	Ft. In.		Inches.	Lbs.	
108	6 x 12	17 — 4	1,269,670	.1241	5,066	Spruce beam, load equally distributed at twelve points. The beam was subjected to a load of 5,031 pounds for 898 hours.
148	4 $\frac{3}{16}$ x 11 $\frac{13}{16}$	17 — 4	1,211,800	.3765	4,668	Yellow pine beam, load distributed equally over twelve points. The beam was subjected to a load of 6,355 pounds for twenty-nine days.

TIME TEST NO. II.

Spruce beams cut in Maine in the spring of 1886. Received at the Institute September 13, 1886. Beams A, B, C, D, E, and F were seasoned under a center load in the laboratory in steam heat from September 15, 1886, to April 2, 1887 (200 days). Beams G, H, I, were seasoned in the same room, but were not loaded. All the beams were without load between April 2 and date of testing. Span = 18′ 00″ for all beams under load.

Beam.	A (194).	B (193).	C (191).	D (190).	E (195).	F (192).
Description of lumber	Clear.	Clear.	Cross-grained.	Knotty.	Straight-grained, some knots.	Straight-grained, some knots.
Dimensions { original	4″ x 12″	4″ x 12 1/16″	3 3/4″ x 11 3/4″	4 3/16″ x 11 1/2″	6″ x 12 1/16″	6 1/4″ x 12″
Dimensions { final	3 13/16″ x 11 1/16″	3 13/16″ x 11 1/16″	3 5/8″ x 11 5/16″	4 1/16″ x 11 15/32″	5 7/8″ x 11 1/8″	5 23/32″ x 11 13/16″
Maximum fiber stress, lbs. per square inch { with weight of beam	1,020	1,011	1,136	994	1,095	1,093
Maximum fiber stress, lbs. per square inch { without weight of beam	966	956	1,075	943	1,037	1,041
Deflection, load first applied	0.3707″	0.4253″	0.5335″	0.4794″	0.5024″	0 5747″
Deflection at end of test	0.9181″	0.8447″	1.2336″	1.0453″	1 0170″	1.5050″
E (immediate)	1,689,000	1,449,000	1,333,000	1,288,000	1,327,000	1,173,000
E (final)	682,000	730,000	577,000	591,000	655,000	448,000
Modulus of rupture, lbs. per square inch { with weight of beam	10,283	7,838	3,243	5,038	7,448	5,116
Modulus of rupture, lbs. per square inch { without weight of beam	10,229	7,783	3,182	4,987	7,392	5,064
Weight per cubic foot at beginning, lbs.	31.8	32.8	35.4	30.0	34.1	30.5
Weight per cubic foot at end, lbs.	28.6	26.1	29.1	27.0	27.7	26.3
Date of testing	April 25, 1887.	April 19, 1887.	April 5, 1887.	April 4, 1887.	April 27, 1887.	April 8, 1887.
E (after seasoning), lbs. per square inch of final section	2,125,500	1,852,300	1,731,600	1,517,800	1,662,100	1,294,100

Average E (immediate) = 1,376,500. Average E (final) = 614,000. Average modulus of rupture, beams under load = 6,494.

Beam.	G (188).	H (187).	I (189).
Description of lumber	Knotty.	Clear.	Knotty.
Dimensions { original	4″ x 12″	4″ x 12″	4″ x 12″
Dimensions { final	3 7/8″ x 11 3/4″	3 13/16″ x 11 5/8″	3 7/8″ x 11 13/16″
Modulus of rupture, lbs. per square inch { with weight of beam	5,218	8,667	4,796
Modulus of rupture, lbs. per square inch { without weight of beam	5,167	8,598	4,751
Weight per cubic foot at beginning, lbs.	29.5	35.8	27.3
Weight per cubic foot at end, lbs.	24.9	29.3	24.8
Date of testing	March 21, 1887.	April 1, 1887.	March 16, 1887.
E (after seasoning), lbs. per square inch of final section	1,355,300	1,914,500	1,573,600

Average E (final section), beams without load = 1,614,500.
Average modulus of rupture (original section) = 6,227.

TIME TEST NO. III.

Yellow pine beams from Georgia, cut in season of 1886. Received at the Institute September 13, 1887. The lumber was purchased in sticks of double length, and cut in two for testing. The numbers indicate the stick, and the letter "B" the butt, and "T" the top end of same. Beams 1T, 2B, 3B, 4T, 5B, 5T, were seasoned under load, the remainder being seasoned without load. Span = 18 feet.

Beam.	1T (238).	2B (239).	3B (240).	4T (241).	5B (242).	5T (243).
Description of lumber	Clear, cross-grained.	Clear, some dry rot.	Clear, straight-grained.	Clear, cross-grained.	Clear, straight-grained.	Clear, straight-grained.
Dimensions, original	4 5/8" x 12 7/8"	4 11/16" x 12 7/8"	4 5/8" x 12 7/8"	3 15/16" x 12 7/8"	6 7/8" x 11 13/16"	6 5/8" x 12 1/16"
Dimensions, final	4 1/16" x 11 13/16"	4 1/16" x 12 1/16"	3 15/16" x 11 31/32"	3 15/16" x 11 31/32"	6" x 11 1/16"	6 1/16" x 11 31/32"
Maximum fiber stress, lbs. per square inch, with weight of beam	1,358	1,259	1,381	1,435	1,626	1,509
Maximum fiber stress, lbs. per square inch, without weight of beam	1,283	1,193	1,302	1,364	1,531	1,426
Deflection, load first applied	0.5310"	0.5518"	0.4700"	0.5618"	0.4431"	0.4836"
Deflection, at end of test	0.9817"	1.2387"	0.9424"	1.4566"	0.8364"	0.8449"
E (immediate)	1,536,000	1,351,000	1,763,000	1,545,000	2,290,000	1,889,000
E (final)	832,000	602,000	879,000	596,000	1,213,000	1,081,000
Modulus of rupture, lbs. per square inch, with weight of beam	6,290	6,234	9,545	6,570	10,630	10,000
Modulus of rupture, lbs. per square inch, without weight of beam	6,213	6,163	9,461	6,495	10,540	9,924
Weight per cubic foot at beginning, lbs.	45.6	40.6	48.2	43.1	50.9	45.8
Weight per cubic foot at end, lbs.	38.4	36.8	43.3	39.0	45.8	41.4
Date of testing	May 22, 1888	May 28, 1888.	May 28, 1888.	May 28, 1888.	May 31, 1888.	June 1, 1888.
E (after seasoning) lbs. per square inch of final section	1,898,000	1,651,000	2,240,000	1,803,700	2,501,400	2,103,400

Average E (immediate) = 1,729,000. Average E (final) = 867,000. Average modulus of rupture, beams under load = 8,211.

Beam.	1B (229).	2T (232).	3T (233).	4B (228).
Description of lumber	Clear, straight-grained.	Dry rot.	Unsound.	Clear, straight-grained.
Dimensions, original	4 1/2" x 12 5/8"	4 5/8" x 12 3/8"	4 5/8" x 12"	3 11/16" x 12 3/8"
Dimensions, final	4" x 11 1/2"	4 5/32" x 12 1/16"	4" x 11 13/16"	3 1/16" x 12"
Modulus of rupture, lbs. per square inch, with weight of beam	9,417	3,069	5,838	9,960
Modulus of rupture, lbs. per square inch, without weight of beam	9,330	3,007	5,754	9,892
Weight per cubic foot at beginning, lbs.	46.1	....	....	....
Weight per cubic foot at end, lbs.	41.4	....	....	....
Date of testing	March 28, 1888.	April 6, 1888.	April 9, 1888	March 26, 1888.
E (after seasoning), lbs. per square inch of final section	2,141,400	1,293,000	1,951,000	1,895,600

Average E (final section), beams without load = 1,820,200.
Average modulus of rupture (original section) = 7,071.

TIME TEST NO. IV.

Spruce from Maine. Green lumber. Received at the Institute September 11, 1888. Beams A, B, C, D, J, K were seasoned under load in the laboratory in steam heat from September 13, 1888, to March 25, 1889 (194 days). Beams E, F, G, and H were seasoned in the same room, but not loaded. All the beams were without load from March 25, 1889, to the date of testing. Span = 18 feet for the beams while under load.

Beam.	A (273).	B (274).	C (276).	D (278).	J (277).	K (275).
Description of lumber	Average stock.	Average stock.	....	Knotty, straight-grained.	Clear, straight-grained.	Clear, straight-grained,
Dimensions { original	4 1/16″ x 11 13/16″	4 1/16″ x 11 13/16″	4 1/16″ x 11 3/4″	4 1/16″ x 11 5/8″	5 1/16″ x 11 13/16″	5 3/16″ x 12″
Dimensions { final	4″ x 11 1/4″	3 15/16″ x 11 5/16″	4″ x 11 5/8″	3 15/16″ x 11 5/16″	5 1/16″ x 11 5/8″	5 1/16″ x 11 5/16″
Maximum fiber stress, lbs. per square inch { with weight of beam	1,422	1,442	1,444	1,436	1,750	1,705
Maximum fiber stress, lbs. per square inch { without weight of beam	1,364	1,385	1,387	1,379	1,698	1,645
Deflection, load first applied	0.6699″	0.7716″	0.6618″	0.7379″	0.8446″	0.7439″
Deflection, at end of test	1.3023″	1.8375″	1.5369″	1.6980″	1.7359″	1.4284″
E (immediate)	1,326,000	1,169,000	1,387,000	1,224,000	1,308,000	1,431,000
E (final)	682,000	491,000	597,000	532,000	637,000	745,000
Modulus of rupture, lbs. per square inch { with weight of beam	7,545	7,211	5,597	6,622	6,484	7,099
Modulus of rupture, lbs. per square inch { without weight of beam	7,487	7,155	5,540	6,565	6,431	7,038
Weight per cubic foot at beginning, lbs.	34.3	33.5	33.0	33.6	31.5	36.4
Weight per cubic foot at end, lbs.	27.3	25.4	26.8	26.9	27.1	28.6
Date of testing	March 26, 1889.	April 3, 1889.	April 9, 1889.	April 11, 1889.	April 10, 1889.	April 8, 1889.
E (after seasoning), lbs. per square inch of final section	1,631,700	1,405,500	1,747,900	1,503,200	1,576,000	1,722,600.

Average E (immediate) = 1,307,500. Average E (final) = 614,000. Average modulus of rupture, beams under load = 6,760.

Beam.	E (270).	F (271).	G (272).	H (251).
Description of lumber	Nearly clear, straight-grained.	....	....	Knotty.
Dimensions { original	3 1/4″ x 12″	4″ x 11 1/8″	3 3/4″ x 12″	4 7/32″ x 11 7/8″
Dimensions { final	3 1/8″ x 11 1/8″	3 1/8″ x 11 1/8″	3 1/8″ x 11 5/16″	4 1/16″ x 11 3/4″
Modulus of rupture, lbs. per square inch { with weight of beam	8,293	7,615	8,558	4,732
Modulus of rupture, lbs. per square inch { without weight of beam	8,237	7,552	8,496	4,676
Weight per cubic foot at beginning, lbs.	33.5	37.2	36.8	33.0
Weight per cubic foot at end, lbs.	27.3	27.6	26.3	27.7
Date of testing	March 13, 1889.	March 19, 1889.	March 22, 1889.	November 6, 1888.
E (after seasoning), lbs. per square inch of final section	1,632,500	1,771,000	1,770,000	1,266,500

Average E (final section), beams without load = 1,610,000.
Average modulus of rupture (original section) = 7,300.

DEFLECTIONS WITH TIME.

The deflection of a timber beam under a long-continued application of the load may be two or more times that assumed when the load was first applied; and, in order to compute it by means of the ordinary deflection formula, we should use for E (the modulus of elasticity) not more than one half the value derived from quick tests.

LONGITUDINAL SHEARING.

Below are given tables showing the greatest intensity of the shear at the neutral axis of each beam at fracture.

TABLE OF BEAMS WHICH GAVE WAY BY LONGITUDINAL SHEARING.

Spruce.		Yellow Pine.		Oak.		White Pine.	
No.	Intensity of Shear, Lbs. per Sq. In.	No.	Intensity of Shear, Lbs. per Sq. In.	No.	Intensity of Shear, Lbs. per Sq. In.	No.	Intensity of Shear, Lbs. per Sq. In.
22	202	30	273	109	152	129	155
24	190	32	242	269	379	134	119
31	154	33	153	..	....	233	180
35	117	50	177	..	....	..	....
36	248	147	264	..	....	..	....
46	233	419	207	..	....	..	....
90	273	429	244	..	....	..	....
304	130	437	289	..	....	..	....
321	233	451	151	..	....	..	....
416	215	452	240	..	....	..	....
421	199	..	....	..	....	..	....
423	207	..	....	..	....	..	....
445	133	..	....	..	....	..	....
450	166	..	....	..	....	..	....
Average, 200.		Average, 224.		Average, 266.		Average, 151.	

EXTRACTS FROM REPORTS OF VISITING COMMITTEES OF THE CORPORATION, MARCH, 1894.

DEPARTMENT OF MECHANICAL ENGINEERING AND APPLIED MECHANICS.

. . . We wish to express our satisfaction at the earnest work that is being done by the students, as well as the progress that is being made in this department in the acquiring and in the use by students of excellent machines and contrivances for making original investigations in the subjects studied, the results of which are additions to the knowledge of the profession. Many of these results are capable of being presented to the profession in such a way as to be a great credit to the Institute. It is certainly true of this department, and is probably true of many other departments of the Institute, that a considerable additional knowledge is attained yearly which the engineering profession is in need of, and it would be valuable to the Institute and to the profession if experimental class work and thesis work were arranged in order to attain such additional knowledge, and provision were made for the prompt publication of such results as were especially valuable as contributions to the knowledge of the profession by the Massachusetts Institute of Technology.

(Signed) Hiram F. Mills,
Francis Blake,
James P. Tolman,
Desmond FitzGerald,
Frank A. Hill.

March 14, 1894.

DEPARTMENT OF MINING AND METALLURGY.

To the Members of the Corporation.

Gentlemen: Your Committee on the Department of Mining and Metallurgy come before you with the same old story presented in former years, so far as relates to the general and efficient management on the part of Professor Richards, and of the inestimable value of the

instruction given by him and his associates. If, however, the oft-repeated statement of the faithfulness and unsurpassed ability of those on whom we depend for thorough work seems almost monotonous by repetition, the record of their doings through the year, and of the accession of improvements in implements required for instruction, can never be otherwise than interesting. . . .

The present year in the Mining Department has been quite a prosperous one. The numbers of students have been larger than ever before. The numbers shown in the President's Report are: For the second year, eighteen; the third year, sixteen; and the fourth year, six, to which should be added ten for the first year, making fifty in all.

During last June the Summer School of Metallurgy made quite a departure from the usual custom by going to Chicago, combining the World's Fair with the visits to and studies of the various metallurgical establishments around Chicago. A party of twelve students attended this school with much pleasure and profit. The work was divided so as to include visits to works upon the alternate days, the remainder of the time being spent in the World's Fair.

One of the immediate tangible results of this visit is in the gifts which certain of the iron manufacturers of Sweden, who are members of the Jernkontoret, or Swedish Iron and Steel Association, made to the Mining and Metallurgical Department of the Institute. These collections show specimens of steel varying in amount of carbon. They show the iron ore and the pig iron from which the steel was obtained. They also show the hammered blooms and billets, as well as test bars and finished bars ready for market. These collections are just now being set up in Room 2 of the Mining Department of the Institute. The works that are especially represented in these collections are Ankarsrum, Söderfors, Horndal, and Österby.

The particular investigations that are being carried on or have just been completed in the department are:

1. The magnetic separation of iron ores from the gangue. For this purpose a new machine, designed by Mr. Chase, of the class of '83, is just now being set up.

2. The separation of graphite from its gangue is being studied by one of the students.

3. The refining of copper by the use of a chloride solution for the separation of silver, gold, and other metals is being tested in the laboratory.

4. Nova Scotia gold pyrite which carries a very large percentage of arsenic is being investigated for the recovery of gold, the high percentage of arsenic offering special difficulties in regard to the extraction.

5. The fusibility of fire clays is being tested by means of a new Deville furnace which has just been provided, and the management of which is now being studied in the laboratory for the first time.

6. An investigation in regard to the laws of jigging has just been completed. The results have brought to light a number of very interesting facts in regard to this method of separation of ores from the gangues. The light which has been thrown upon the principles of jigging will prove of value in the designing of mills for concentration.

The plan for the next Summer School is developing, and the school will probably be held in Nova Scotia and Cape Breton.

As preparation for this summer school some of the new stadia measures that have recently been designed for the Mining Department are being made by Alvan Clark & Sons, of Cambridgeport. For rapidity and accuracy this stadia excels all others.

The library is receiving additions of valuable books, not only in keeping up the running files of periodicals, but new works on the subject are being added from time to time in order that the latest and freshest data may be on hand for reference by the students. During the last year the files of *Thonindustrie Zeitung* and of *Stahl und Eisen* have been completed, and a new annual has been added, the *Freiberger Jahrbuch.* These additions were chosen partly with reference to the representative character of the periodicals, so that the library may be as representative of the departments of mining and metallurgy as possible, and partly also with reference to the students' work of writing abstracts of professional memoirs. This department of instruction is becoming more and more valuable as the years go on. . . .

Respectfully submitted,

(Signed) THOMAS T. BOUVÉ.

Boston, March 14, 1894.

ARCHITECTURAL DEPARTMENT.

To the Members of the Corporation.

GENTLEMEN: The past year has been one of the most successful in the life of the Architectural Department, both in regard to the number of students and the quality of the work accomplished. This year there are fourteen candidates for a degree. This year also there has been a post graduate class of six, and this year also has brought the largest number of skilled draughtsmen from offices to increase their knowledge of mathematics and design.

The chief interest of the year has been in connection with the new professor of design, M. Despradelle. He entered a field filled with the strongest memories of the ability of his predecessor, Professor Létang, but he has held his own, and his success as a teacher is assured. He is ambitious for his scholars and expects much of them, and they in turn are greatly attracted towards him.

There has been added to the plant this year for instruction in architectural history some six hundred lantern slides. These have all been made in the department at about one quarter the cost if purchased outright. The Art Museum has a fine collection of slides devoted principally to decorative subjects, and as we loan to each other we avoid entering each other's fields.

There is a steady improvement in the standard of drawing, and consequently in design. The drawing has been accomplished by most careful instruction from the cast and from life, and it has been greatly aided by the beautiful "Envois" drawings which, through the courtesy of the Rotch trustees, decorate the walls. These drawings have been hung in the hallways, so that every one can be seen and carefully studied. The freehand drawing could be still much improved, but it needs another assistant, which we do not hope for in the present state of the school's finances. The sections are too large; instead of from forty to seventy, as at present, the section should not contain more than fifteen to twenty students. The students complain of not getting enough of individual instruction. Again, many of our students are irregular; that is, five year students, or college graduates, or other specials. They must often lose this course in freehand drawing on account of some other study appointed for the same hour. In case of such conflicts the corps should be strong enough to have other sections. No student should be handicapped by losing this course.

Last year was a first attempt at a summer school, and the exhibition of work done at Chicago clearly showed the value of such a course. This year we propose to continue the scheme if it meets the approbation of the Executive Committee. The work this time will be among the colonial houses of Salem, Portsmouth, and vicinity, and we hope for such good work to be done that it can be published for the glory of the Institute.

At M. Despradelle's request that his initial work with the students should not be judged too early, the usual committee from the Boston Society of Architects did not visit the monthly work of the students; but the final result of this year's work is now ready and makes a brilliant showing. Next year the Committee of Architects will resume judging the work of the department monthly, for there is great stimulus to the students in the sympathy and criticism of well-known practicing architects.

Respectfully submitted,

(Signed) ARTHUR ROTCH,
ELIOT C. CLARKE,
JOHN R. FREEMAN.

May, 1894.

CHEMICAL AND BIOLOGICAL DEPARTMENTS.

Mr. President and Gentlemen of the Corporation.

The Chemical Department has been, of course, severely tried by the loss of Professor Norton; but the department has much to congratulate itself upon in the lecturers upon special subjects, whose ability and thorough knowledge of their themes have been very remarkable. . . .

One of the most distinguished of modern European industrial chemists in a report on the World's Fair has said to the chemical manufacturers of Europe: "The manufacturer finds in the United States the most favorable conditions for production of all the heavy chemicals, with the single exception of potash salts, and although these advantages have not been fully utilized as yet, it would surely be folly to hope that they will long be neglected. He who looks about him while there will surely not expect this, whether he may wish it or not."

The quotation shows what a foreigner speaking to foreigners thinks, we may even say fears, as to our opportunities for supremacy in industrial chemistry, and only accentuates what we have before suggested, that the subject should be made as important in the Institute as any other, and will well repay the fostering care expended to make it so. . . .

Additions to the staff of the Biological Department this year have rendered the force fully able to give the necessary instruction, and the liberal expenditure on apparatus has supplied all that was wanted for the time being in that respect. While the number of students in the regular course of biology remains nearly constant, the usefulness of the department to the school steadily increases. Instruction is now given by this department to students in civil engineering, architecture, chemistry, physics, sanitary engineering, geology, and the general course, as well as to those in biology. More than one hundred and fifty pupils have this year come under instruction in this department. The greatest difficulty is that the laboratory is far too small. Three times the present space could be well used, and would be none too much for the present needs. Moreover, if more room could be had it would be easy to increase the attendance by the addition of students in farming and some branches of manufacture, to whom a knowledge of bacteriology and the changes wrought by living organisms are now known to be essential.

(Signed) SAMUEL CABOT,
CHARLES C. JACKSON,
JAMES M. CRAFTS.

Boston, March 9, 1894.

DEPARTMENTS OF PHYSICS AND ELECTRICAL ENGINEERING.

To the Corporation of the Massachusetts Institute of Technology.

The Committee on Physics and Electrical Engineering have the honor to report that their visit to the department has disclosed a marked improvement in methods and results during the past year.

The pressing needs of the department mentioned by the Committee in their report of last year have been met most satisfactorily by the assignment of an assistant in charge of the library, and the equipment of a station where observations of precision can be carried on with a practical freedom from outside electrical and mechanical dis-

turbances. Apparatus and results bear witness to much original research by Professor Cross and his assistants during the year.

The Committee have been particularly impressed by the ingenious apparatus and experiments which have enabled Professor Cross to establish the new physical fact that differences in pitch may be noted by a comparison of fractional parts of simple sound waves; by the apparatus contrived by Professor Holman and Mr. Laws for the measurement of currents up to 300 amperes with an accuracy never before attained in such measurements; by Mr. Laws' work upon a "sine dynamo;" and by the beautiful apparatus with which Professor Puffer illustrates the effects of "three phase" currents.

During the year Professor Holman has published a revised and much enlarged edition of *Physical Laboratory Notes, Part II.* The value of this volume as an aid in educational work can hardly be overestimated, and it is certainly not too much to say that for many years to come it will be a worthy memorial of its author's scientific attainments and rare ability as a teacher.

The existence of so able and zealous a professional staff as it is now the privilege of this department to possess connotes a never to be satisfied need of increased facilities for scientific work. The Committee are well aware, however, that the finances of the Institute may not permit any large expenditures for such purposes during the coming year. Nevertheless, it should be borne in mind that, if the Institute is to hold its position in the van of educational progress, provision must be made for the establishment, in the near future, of a physico-chemical laboratory. At the outset an additional room in the Walker Building and a moderate amount of inexpensive apparatus would meet this want.

The dynamo room, as at present equipped, is taxed to its utmost capacity in the matter of lighting the Institute buildings. Aside from the first cost, it would doubtless be an economy to provide a more powerful engine and two additional dynamos. Such an installation would be of general benefit to the Institute and of particular benefit to advanced thesis work in the Department of Electrical Engineering. . . .

Respectfully submitted by

(Signed) FRANCIS BLAKE,
CHARLES W. HUBBARD,
A. LAWRENCE ROTCH,
Committee.

CHANGES IN THE CORPS OF INSTRUCTION.

(Corrected to October, 1894.)

Associate Professor Despradelle, who came to the Institute from Paris last fall, is appointed professor of architectural design.

Arthur A. Noyes, Ph.D., Augustus H. Gill, Ph.D., and Fred L. Bardwell, S.B., now instructors in the Chemical Department, become assistant professors.

Assistant Professor Vogel, of the Department of Modern Languages, returns from a year's study at the University of Heidelberg.

The following assistants have been promoted to instructorships:

Herbert R. Moody, S.B., in analytical chemistry.

Joseph P. Lyon, S.B., in civil engineering.

Charles E. Fuller, S.B., William A. Johnston, S.B., and Charles F. Park, S.B., in mechanical engineering.

Robert S. Shedd, in architecture.

Charles M. Faunce, A.B., in mechanical drawing and descriptive geometry.

Frederick S. Woods, Ph.D., and Henry M. Goodwin, Ph.D., return after study in Germany to resume their instructorships in mathematics and physics, respectively.

William H. Walker, Ph.D., becomes an instructor in analytical chemistry in place of Mr. Davenport. The latter and Mr. W. R. Whitney go to Germany for further study of chemistry.

John Osborne Sumner, A.B., has been appointed instructor in history.

The following instructors are no longer connected with the Institute: Edward Collins, Jr., William H. Metzler, Robert Ball, Johann Meyer, Edson L. Whitney.

AWARD RECEIVED AT THE WORLD'S COLUMBIAN EXPOSITION, CHICAGO, 1893.

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For original researches carried on in chemistry, biology, electricity, and other specialties.

For designs for textile fabrics by the students of the Lowell Free School, a branch of the Institute, showing intelligent appreciation of the need of adapting designs to the processes and machines of manufacture.

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For arrangements and devices for administration as conducted by Gen. Francis A. Walker, President.

(Signed) WILLIAM W. FOLWELL,
Individual Judge.

Approved. DR. K. BUENZ,
President Departmental Committee.

Approved. JOHN BOYD THACHER,
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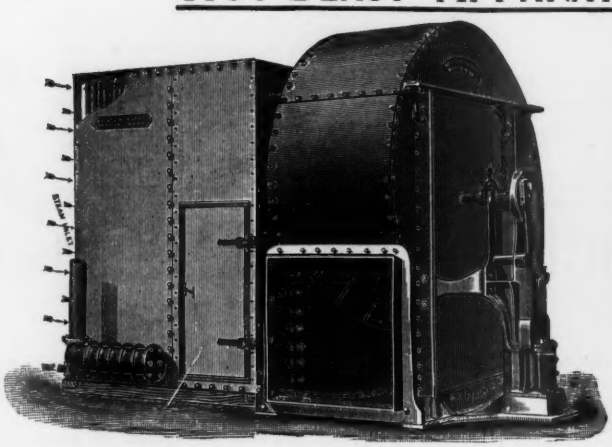

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